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SCIENTIFIC MISSION SUPPORT FOR EXTENDED LUNAR EXPLORATION

Final Report

Volume 2

Task Summary

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FOREWORD

This document contains the Task Summary Report concerning the results of a study of Scientific Mission Support for Extended Lunar Exploration. The study was performed by the Space and Information Systems Division of North American Aviation, Inc. for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration under Contract NAS8-20258.

The study was performed under the technical direction of Dr. N. C. Costes of the Research Projects Laboratory of NASA-MSFC, during a 7-1/2-month period beginning 13 December 1965. The general guidelines of the study were stipulated in DCN 1-5-21-00019 (1F).

The complete results of the study are presented in the following volumes:

Volume 1 - Condensed Summary Report

Volume 2 - Task Summary Report

Volume 3 - Detailed Technical Report

Volume 4 - Appendix A, Experiment Sequences - Computer Printouts

Volume 5 - Appendix B, Master Data Report - Computer Printouts

Volume 6 - Appendix C, Computer Program

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ILLUSTRATIONS

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TABLES

GLOSSARY OF TERMS

AAP	- Apollo Applications Program (formerly AES, Apollo Extension Systems)—A concept for continuing the exploration of the Moon and near-Earth space through maximum utilization of existing Apollo hardware.
ALSEP	- Apollo Lunar Surface Experiment Package—A package of geophysical instruments to be carried on early Apollo manned lunar flights which will be emplaced by the astronauts on the lunar surface and left there to record and transmit to Earth lunar geophysical data for periods up to one year.
Apollo	- The total system for accomplishing the initial manned lunar landing.
Bev	- One billion electron-volts.
COBOL	- A computer language or technique commonly used to encode business computer programs usually related to financial data.
Discipline Area	- A principal division of science or engineering. The SMS-ELE Discipline areas are:

(0) Lunar Atmospheres
(1) Geodesy
(2) Geology
(3) Geochemistry
(4) Geophysics
(5) Particles and Fields
(6) Biology
(7) Astronomy
(8) Mission Support Investigations
(9) Miscellaneous Basic and Applied Research

ESS	- Emplaced Scientific Station—A geophysical observatory containing a complex of instruments similar to the ALSEP but of larger size.
Experiment	- A series of measurements or observations intended to yield specific information required to accomplish part of an investigation. An experiment may have one or

		more replications; e.g., (1) measurement of material density; (2) observation of petrologic character; e.g., crystalline, amorphous, sedimentary, igneous, metamorphic, etc.
GSFC	-	NASA Goddard Space Flight Center
Investigation	-	An exercise involving a group of closely related experiments performed concurrently and/or sequentially with the intent of acquiring a specified amount of a particular kind of information within a technical area. Example: (1) determination of the number and relative amounts of different minerals in a given area; (2) photographic survey of the lunar equatorial region with a specified degree of optical resolution. An investigation can consist of one experiment only, in which case, the terms "experiment" and "investigation" are synonymous.
LEM	-	Lunar Excursion Module of the Apollo
LEM-SHELTER	-	A LEM modified to permit lunar landing and up to a three-month quiescent lunar surface storage, followed by a two-week manned occupancy as a lunar base and laboratory.
LEM-TAXI	-	A LEM modified to permit up to a two-week unmanned storage on the lunar surface after landing by crew adjacent to the LEM-SHELTER and prior to return to Earth.
LEM-TRUCK	-	A LEM descent stage modified to operate as an unmanned payload carrier. Reaction control systems must be added to permit this flight profile. Such a logistics carrier could deliver as much as 10,000 pounds of payload to the lunar surface using the basic Apollo mission profile.
LESA	-	Lunar Exploration System for Apollo—A post-Apollo modular lunar base concept accommodating from 3 to 18 men, with lunar surface stay-time capabilities ranging from three months to more than two years.
LSSM	-	Local Scientific Survey Module—A short-range (action radius 8 to 10 kilometers, maximum range of single traverse 25 kilometers), open-cabin surface vehicle, carrying one or two astronauts and containing neither

		environmental control nor life support systems. Portable backpacks are the sole provision for life support with this mobility.
Mev	-	One million electron-volts
MIMOSA	-	Mission Modes and System Analysis for Lunar Exploration—MSFC Study Contract NAS8-20262 with Lockheed Missiles and Space Company
MHz	-	Megahertz (1 million cycles per second)
MOLAB	-	A concept for a long-range mobile laboratory. The concept was initially associated with the Apollo Logistics Support System concept.
MSC	-	NASA Manned Spacecraft Center, Houston, Texas
MSFC	-	NASA Marshall Space Flight Center, Huntsville, Alabama
NAA	-	North American Aviation, Inc.
NAS	-	National Academy of Sciences
OART	-	NASA Office of Advanced Research and Technology
OCE	-	Office of the Chief of Engineers, Department of the Army
OMSF	-	NASA Office of Manned Space Flight
OSSA	-	NASA Office of Space Sciences and Applications
RTG	-	Radioisotope Thermoelectric Generator - energy sources connected with the ALSEP and ESS.
S&ID	-	Space and Information Systems Division of North American Aviation, Inc.
SMS-ELE	-	A study of Scientific Mission Support for Extended Lunar Exploration (this study)
USGS	-	United States Geological Survey

1.0 INTRODUCTION

1.1 BACKGROUND

This report presents the results of a study conducted to define the probable extent of scientific investigations to be accomplished in extended lunar exploration and to provide an estimate of experimental systems and operational requirements for typical lunar programs.

The Apollo Program has the immediate objective of landing two men on the lunar surface and returning them safely to Earth. With this operational capability approaching reality, one of NASA's major tasks is the determination of the most satisfactory use of this operational capability or some combination of its elements. Because of the long lead times associated with upgrading capability or modifying existing space systems, or with the development of advanced systems, it is important at this time to study various scientific missions and the associated support requirements.

The Scientific Mission Support Study for Extended Lunar Exploration is a second-generation study that builds on the results of previous first-generation studies that examined potential missions for specific system concepts such as the LEM/SHELTER-LEM/TAXI, the ALSS-MOLAB, and LESA. This study differs from the preceding studies in that it is not subject to the restraints of a single candidate system; however, the general system and subsystem capabilities anticipated for the applicable phase of lunar exploration are considered.

1.2 STUDY OBJECTIVE

The primary objective of this study is to provide an estimate of experimental systems and operational requirements for typical lunar scientific programs to establish scientific mission requirements to influence the definition of future lunar exploration systems. These systems and operational requirements, imposed by the science program on the lunar mission equipment, represent a vital input to the study of systems requirements for an evolutionary program of lunar exploration.

The results of this study provide information to be used for the Mission Modes and Systems Analysis for Lunar Exploration (MIMOSA), a study currently being performed by Lockheed Missiles and Space Company under Contract NAS8-20262, and for other NASA studies of systems for lunar exploration.

1.3 STUDY GUIDELINES

The initial guidelines provided by NASA for the study were as follows:

1. Scientific guidelines should be derived from the report of a study conducted by the Space Science Board, entitled "Space Research—Directions for the Future" and from the report of the NASA 1965 Summer Conference on Lunar Exploration and Science (References 1 and 2). Fundamental experiments should be compiled from References 1 and 2 and other NASA source documentation.

2. The results of previous scientific mission support studies relating to single-point candidate systems for extended lunar exploration that are pertinent to the expanded scope of this study should be used.

3. Scientific mission definition should not be tailored to constraints imposed by a specified transportation mode for a particular period; nor should they be restricted to missions associated with specific lunar base candidate systems.

4. Some understanding of the practical limits and general utility of the proposed AAP effort should be acquired to assess the extent that the early effort of lunar exploration can influence the later phases of the program.

5. An assessment of the penalty to the scientific effort by the lack of adequate personnel mobility should be made.

6. A reasonable effort should be made to understand and to factor into this study the relationship between scientific exploration growth and the possible growth patterns and development modes that will comprise the personnel and logistics transportation and the lunar base system capability.

7. The study results should serve as an input to the concurrent Mission Modes and System Analysis Study (Reference 4).

Other guidelines evolved throughout the study as a result of coordination with NASA personnel and the MIMOSA contract. The most significant action items resulting from these directives were:

1. Key data cards from the NAA experiment data management systems were used as direct input cards to the Lockheed MIMOSA computer program, as a source of data on scientific experiments, their support requirements, and their required instrumentation and equipment.

2. Applicable inputs in the geosciences area from the Bendix Systems Division, the subcontractor to Lockheed and responsible for certain MIMOSA scientific activities, were incorporated to the maximum extent possible.

1.4 APPROACH

To facilitate exchange of information between this study and the Lockheed MIMOSA Study, this study effort was organized into two phases. During Phase I, source documents (see Section 8.0, Volume 3) were screened for identification of potential experiments. Typical source documents consisted of NASA contractor reports, conference proceedings, scientific subgroup meetings, and NASA in-house study reports. NASA-supplied scientific objectives and guidelines were used as selection criteria. Key guidelines documents included "Space Research—Directions for the Future," (Reference 1) a report of a study by the Space Science Board of the National Academy of Sciences conducted at Woods Hole, Massachusetts, during the summer of 1965, and the proceedings of the NASA 1965 Summer Conference on Lunar Exploration and Science (Reference 2). These documents were also used as sources for experiments and investigations.

The initial review of source documents and guidelines was translated into scientific goals or objectives, experiments, and operational support requirements. It also resulted in equipment parameter definition and supported the identification of some mission support experiments and experiments of a basic and applied research nature.

Potential experiments were initially listed from approximately 90 documents supplied by NASA. This initial listing produced approximately 660 experiments. Since these experiments came from many separate documents, it was inevitable that there would be duplications and redundancies. Duplicate experiments were removed, and overlapping experiments were combined by expanding the scope of one experiment so that, with minor redefinition, it could accomplish the aims of two or three experiments. These redundancy checks, commonality identifications, and revisions following the mid-term review resulted in a total of 340 experiments. In the future, the number of experiments will probably be altered as additional knowledge concerning the Moon and system support capabilities becomes available.

The experiments, arranged by scientific discipline area, were submitted to NASA for analysis and review by NASA and by selected scientific and engineering groups. Figure 1 shows the review process and the reviewing agencies and groups. The results and comments of this review were factored into the final data presentation by NAA through the Marshall Space Flight Center. With the information gained from the activities previously

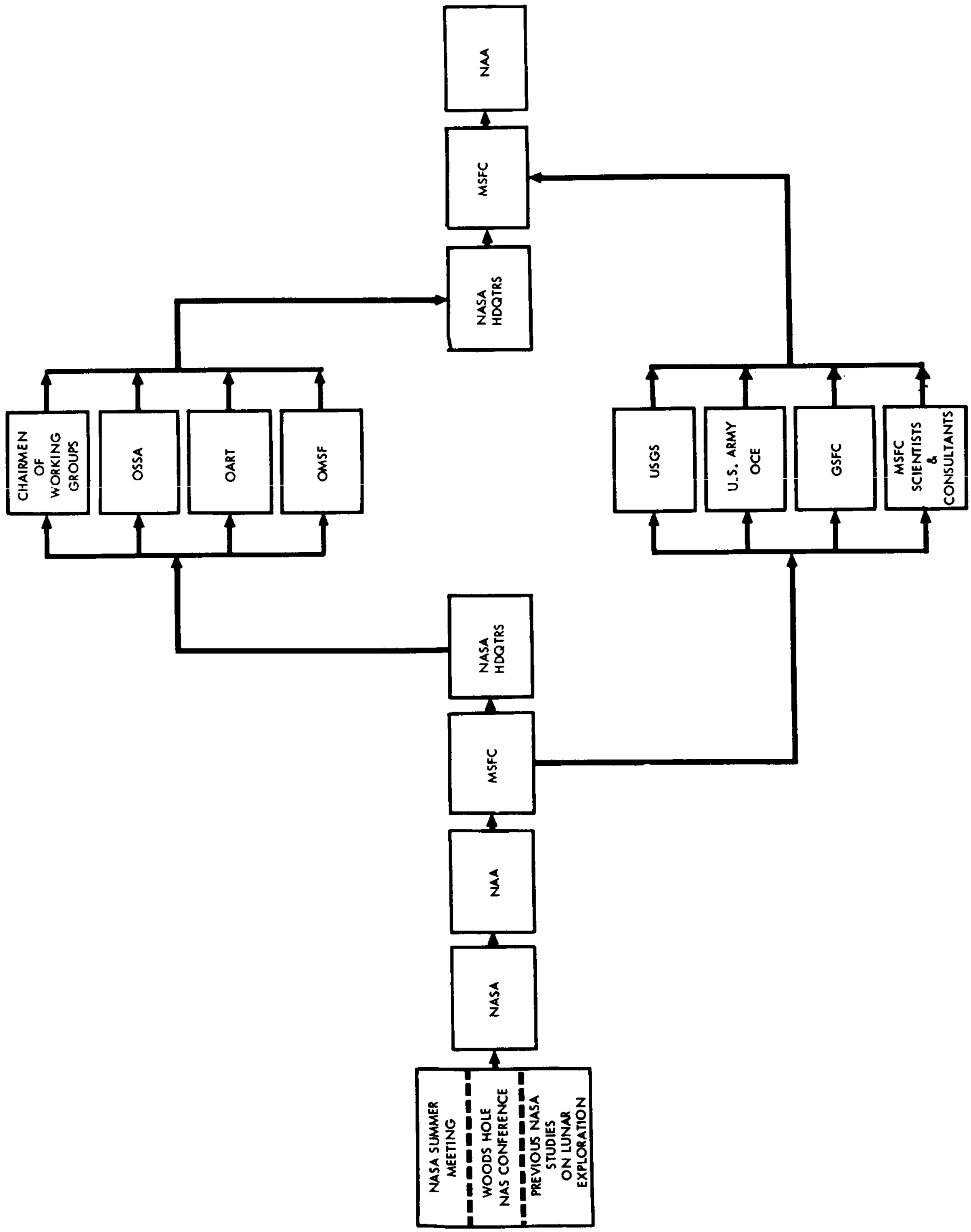

Figure 1. Experiment Review Process

delineated and from NAA experience in lunar scientific and operational studies, a data-handling procedure was developed that evolved into an experiment data management system (Figure 2).

Figure 2 also illustrates the generation of the master experiment list, the subsystem support requirements, equipment performance requirements, and the mission support requirements as a second-level effort, with its gradual evolution into the experiment cataloging activity, which consists of the formulation of various sequences. The second-level effort essentially completed Phase I activities, although continuous experiment updating was performed throughout Phase 2 as more information became available.

Phase 2 activity was concerned with formulating experiment sequences to identify logical exploration phases and the interdisciplinary relationships of experiments, based on experiment support requirements. Implications of mobility, both short- and long-range, were investigated and related to the predicted lunar astronaut capability, based on data presently available. System/subsystem unique requirements were studied for transport and emplacement of special large scientific facilities, and the requirements of the lunar scientific program for qualified scientific personnel were assessed.

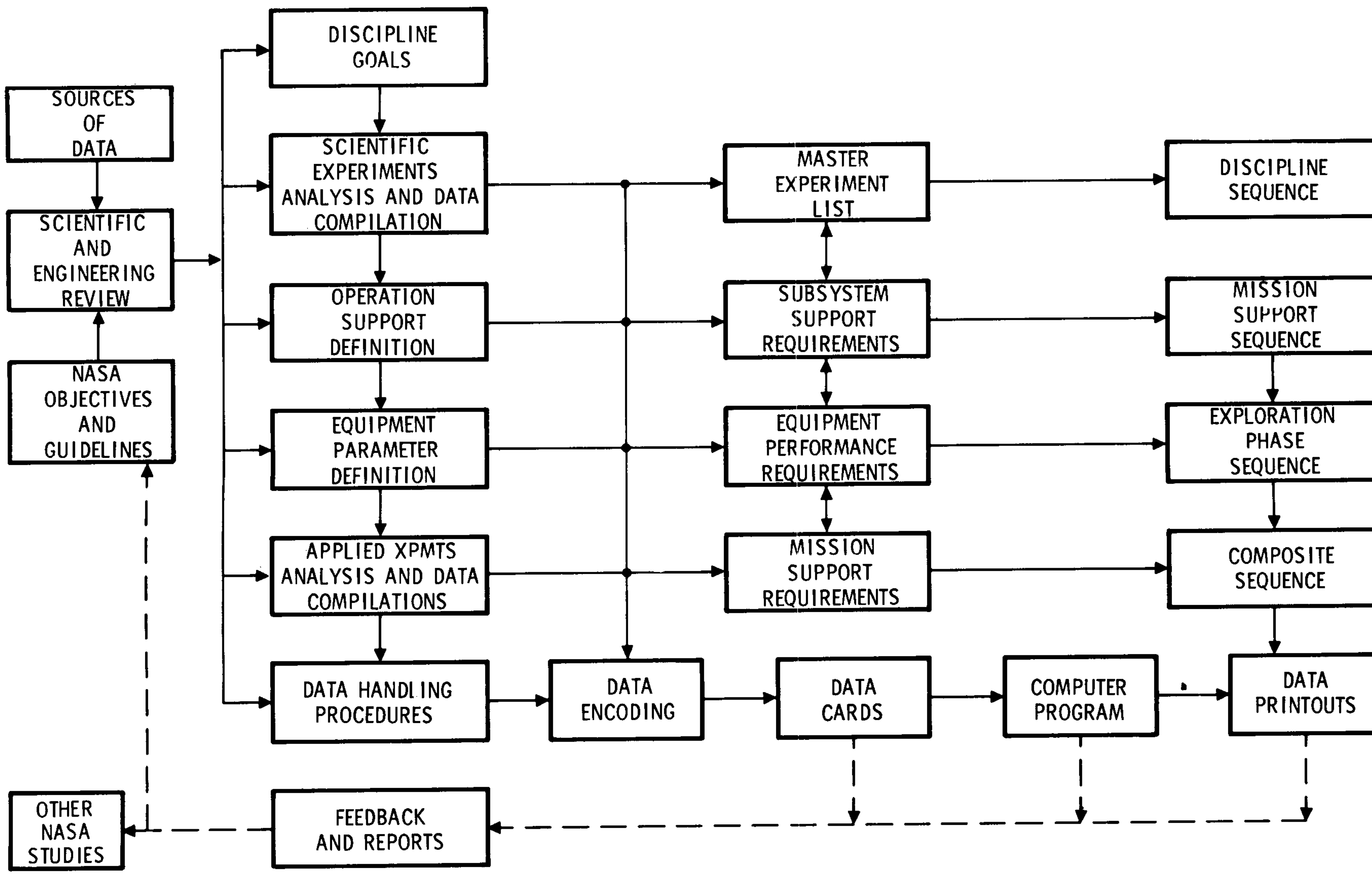

Figure 2. Project Data Flow

2.0 SUMMARY OF RESULTS

2.1 EXPERIMENT ORGANIZATION

The experiments were organized into three main categories: Fundamental Investigations, Mission Support Investigations, and Miscellaneous Basic and Applied Research.

For the purposes of this study Fundamental Investigations include experiments to be conducted on the lunar surface and from lunar orbit to provide scientific data for answering fundamental questions regarding the history, origin, environment, and properties of the Moon and the universe.

Mission Support Investigations include experiments that (a) contribute to the effectiveness and aid the planning and sequencing of Fundamental Investigations by providing essential engineering information relating to the lunar environmental conditions; (b) provide technological data for upgrading engineering systems and subsystems and optimizing operations performed in the lunar environment; and (c) are designed to assess the feasibility of lunar resources.

Miscellaneous Basic and Applied Research includes research activities performed during lunar operations that are not directly oriented to answering fundamental questions but take advantage of the lunar environment to extend basic and applied scientific knowledge.

The Fundamental Investigations were organized into eight scientific discipline areas as follows:

Area	Title
0	Lunar Atmospheres
1	Geodesy
2	Geology
3	Geochemistry
4	Geophysics
5	Particles and Fields
6	Biology
7	Astronomy

The two other categories were identified respectively Discipline Areas 8 and 9:

Area	Title
8	Mission Support Investigations
9	Miscellaneous Basic and Applied Research

Experiments under the category "Fundamental Investigations" were compiled from NASA source documentation. Experiments included in the categories "Mission Support Investigations" and "Miscellaneous Basic and Applied Research" experiments were mainly defined by NAA.

2.2 STUDY TASKS

The following general study tasks were accomplished:

1. A typical spectrum of Fundamental Investigations was extracted by reviewing existing suggested experiments and investigations and analyzing presently approved programs.

2. Mission Support and Miscellaneous Basic and Applied Research experiments were identified to ensure a more complete assessment of the total experiment support requirements.

3. Equipment, personnel, and operational requirements were identified for each experiment or investigation.

4. A study was made of system/subsystem requirements associated with astronaut suit technology, mobility, and special large observatories.

5. An experiment data management system was developed that allows rapid retrieval of data pertinent to experiment definition and associated support requirements.

6. Within each scientific discipline the fundamental experiments were ordered:

    a. In terms of logical scientific accomplishment.

    b. By ascending mission support requirements.

    c. In exploration phase sequences to identify logical phases of lunar exploration.

7. Composite Sequences, across scientific disciplines, were formulated for each exploration phase identified in item 6c above.

8. Program planning contingencies associated with possible changes in certain facets of current theory and hypothesis concerning the Moon were considered.

9. Requirements for qualified scientific personnel, imposed by the lunar scientific program, were reviewed.

Figure 2 shows the task flow of activity for the major tasks. The activity flow was generally from left to right and, simultaneously, from the top toward the bottom of the figure.

2.3 FUNDAMENTAL EXPERIMENTS COMPILATION

There are 235 fundamental experiments compiled from NASA source documentation in the present data management system. These experiments are organized within 85 investigations. The number of experiments compared to the number of investigations may be considered to be small; however, the investigations were formulated with a future growth in the number of experiments anticipated as lunar exploration progresses. The present number of experiments is considered to represent an adequate scientific coverage in view of the limited knowledge of the lunar surface, the definition of actual scientific equipment and instrumentation, and the capability of the supporting systems. As more knowledge is acquired of the lunar surface and eventual mission-systems support capability, and as the experiment and associated equipment become better defined, the experiments may be better defined and the number of experiments may accordingly be altered.

Table 1 lists the total number of experiments for each scientific discipline area and includes a summary of the Mission Support and Miscellaneous Basic and Applied Research experiments.

2.4 MISSION SUPPORT AND MISCELLANEOUS BASIC AND APPLIED RESEARCH INVESTIGATION CATEGORIES SUMMARY

Mission Support and Miscellaneous Basic and Applied Research investigation categories were established for this study to obtain a more complete definition of the investigations and experiments associated with lunar scientific missions. In general, the investigations that comprise Discipline Areas 8 and 9 directly support the performance of fundamental investigations, advance capabilities for exploring the Moon, extend basic knowledge of Earth-oriented applications, and support the development of a technology base for exploration of the planets and observation of the Universe.

The general organization of Discipline Areas 8 and 9, and the numerical distribution of investigations or experiments within these areas is shown in Table 2.

Table 1. Experiment Compilation

Discipline Area	Number of Experiments	
	Lunar Surface	Lunar Orbit
Lunar Atmospheres	6	0
Geodesy	5	2
Geology	12	2
Geochemistry	19	4
Geophysics	84	10
Particles and Fields	44	3
Biology	7	0
Astronomy	34	3
Total Number of Fundamental Experiments	211	24
Mission Support Investigations	90	6
Miscellaneous Basic and Applied Research	9	0

Table 2. Discipline Areas 8 and 9 Organization and Experiment Compilation

Discipline Area	Functional Specialty Grouping	Number of Experiments
8. Mission Support Investigations	Engineering model of lunar surface and environment	19
	Direct support to fundamental investigations	16
	Biomedical, human factors, and life support	18
	Exploration systems and subsystems technology	27
	Mobility and deployment support	7
	Resources utilization feasibility	9
	Total	96
9. Miscellaneous Basic and Applied Research	Basic experiments utilizing lunar environment	4
	Advanced technologies utilizing lunar environment	5
	Total	9

2.5 EXPERIMENT DATA MANAGEMENT

A data processing and retrieval technique for compiling and displaying experiment data, equipment data, and mission support requirements was developed during the program to provide lunar exploration mission planners with a tool for evaluating system/mission tradeoffs and to provide a compilation of vehicle and system support requirements and design criteria in terms of the principal scientific investigations recommended by the scientific community.

The experiment data management system has the following characteristics, which are necessary to satisfy the program requirements:

1. The system is flexible to accommodate future known and unknown requirements as the need becomes clear to define those requirements.

2. It has a large potential capacity to accommodate large numbers of experiments as the investigations and experiments become better defined and can be divided into manageable discrete units of accomplishment.

3. It is capable of primary use in constraint analysis to aid in future mission planning efforts concerned with system effectiveness.

4. It is simple, and quickly and conveniently useful to the uninitiated, and it allows maximum use of human judgment.

The data management system is organized around six types of IBM computer card formats for purposes of experiment description. Additional cards may be introduced for purposes of describing specific subsystem requirements. A seventh card, providing the capability for more detailed requirements concerning telemetry, has been added to the computer program. A more detailed description of the data management system is presented in Section 6.0.

2.6 ASTRONAUT LUNAR CAPABILITIES

A major portion of the suited astronaut energy expenditures in lunar surface operations may be associated with two types of activities, surface travel and execution of relatively stationary work tasks. During these operations, the astronaut will perform in environments that have been shown by experimentation from a cross section of sources to produce significant decrements in the productivity, capability, and efficiency of operators.

Based on present data from preliminary tests, time multiplication factors which may be used to estimate task times for a man in a lunar suit should be roughly two times the total time estimated for walking in shirtsleeves and four times the total time estimated for specific work tasks to be performed in shirtsleeves. A single average factor of three times the total time estimated for performing operations in shirtsleeves can be used for estimating the time required for general operations in a lunar suit. Correspondingly, an average energy output by the operator of approximately 1200 to 1300 Btu per hour should be allowed, and more rest periods should be programmed. Force production capabilities of no more than 50 to 60 percent of Earth values can be anticipated, and are a function of the nature of the force requirement. At times, considerably less force production capabilities may be realized. Bracing-restraint systems should be provided during the production of prolonged work.

2.7 MOBILE SYSTEMS

Of the total number of experiments compiled for lunar exploration during the study effort, 71 specified requirements for no mobility, 147 specified requirements for walking mobility, 73 specified requirements for at least short-range mobility (less than 15 kilometers) and 45 specified requirements for long-range mobility (100 kilometers or greater).

Early lunar exploration will require local, short-range vehicles of the LSSM type to increase mobility of the suited astronaut for the following reasons: reduce man-hours for surface locomotion; reduce astronaut fatigue; support the astronaut in the performance of investigations and experiments; provide mounting for sensors and operational equipment; provide support, such as power and data management; extend allowable duration of local exploration and/or deployment activities; increase operating radius for early exploration; transport equipment and supplies; and increase probability of mission success.

To provide optimal local exploration support, the short-range mobile systems must extend the effectiveness and safety of the astronaut in conducting a range of investigations. More than a personnel and logistics carrier, the LSSM should evolve as a primary component in the integration and execution of experiments.

The study indicates that extended surface traverse and support capabilities are required to:

1. Obtain an integrated broad regional picture of the surface geology and crustal structure of the Moon and integrate local detailed studies

made during the early lunar exploration phase. Long traverses are also needed to correlate and interpret the data obtained from orbital vehicles and unmanned lunar probes

2. Extend terrain negotiability to permit surface travel to areas of major geological significance

3. Extend the duration capability for manned traverses consistent with range and with extended traverse site operations

4. Provide the investigation and experiment support functions described for the LSSM, but on a scale consistent with increased size, duration, and complexity of extended-duration investigations

5. Provide on-board analytical facilities for timely interpretation and correlation of findings

6. Provide a basic mobile operations support capability which, through specialized modular additions, makes possible the deployment and installation of major scientific facilities, such as a long-wave radio telescope and a 100-inch telescope for the lunar astronomical observatory, described in Sections 5.3.1 and 5.3.2.

2.8 LUNAR SURFACE SCIENTIFIC OBSERVATORIES

A study was made to determine special support requirements that may be unique in the emplacement of special scientific facilities for extended lunar exploration Astronomy has the major requirements for these facilities; therefore, two typical scientific observatory-type facilities were studied in some detail: an antenna installation for lunar long-wave radio astronomy and an optical astronomy observatory facility encompassing a large 100-inch-aperture telescope.

There appears to be no special problem for either type of installation. Packaging requirements are flexible, although a special payload design will be required for optical astronomy. The surface deployment requirements can be satisfied by mission support equipment presently envisioned for the middle phases of extended lunar exploration, including the addition of special construction modules attached to the long-range mobile vehicles

2.9 EXPERIMENT SEQUENCING

The experiments were organized into four separate sequences to provide a tool for evaluating the implication of alternate program decisions concerning costs, schedules, operations, and requirements for development of lunar exploration systems. The sequences were developed as follows:

1. The Discipline Sequences group the experiments within each discipline according to a logical order of scientific accomplishment.

2. Mission Support Sequences order the experiments within each discipline by increasing mass, energy, and man-hour requirements. These sequences show the distribution of the critical parameters and can be used to evaluate combinations of experiments that may be used in mission planning. They are useful tools in developing other sequences.

3. The Exploration Phase Sequences order the experiments of each discipline area into successive phases of lunar exploration compatible with progressively ascending levels of scientific knowledge and operational capabilities.

4. The Composite Sequences are interdisciplinary ordering of experiments within each of the exploration phases identified in Item 3.

Five logical phases of lunar exploration, based on experiment support requirements, were identified during experiment sequencing. Phases A and B were considered to be early lunar exploration, with Phase A being the period of initial lunar landing. Phase C was considered a transitional phase to extended lunar exploration Phases D and E. Each phase represents progressively greater operational capability.

A typical result of the sequencing is illustrated in Table 3, which presents a man-hour summary by exploration phase. It should be noted that in this table experiment repetitions are not included. This consideration is a function of mission planning which was not considered. Also, the hours presented are for experiments considered to be within the capabilities of a particular phase, but not necessarily recommended for that phase. Consequently, the experimentation hours for Phases A and B may be considered high. However, the hours for Phase C should possibly reflect the cumulative total of hours for the preceding Phases A and B to be more realistic since many experiments of early phases will also be repeated during the later phases.

It is interesting to note that if the assumption is made that, for each astronaut, 8 of every 24 hours is used for the performance of experiments on the lunar surface, approximately 4790 man-days (Earth days) would be required on the lunar surface to perform each experiment once. If it is assumed that three men will be on the lunar surface during the extended phases of lunar exploration (Phases C, D, and E), approximately four years

Table 3. Man-Hour Summary

Phase	Total Experimentation (man-hours)	Space Suit* (man-hours)
A	140	30
B	2,810	870
C	8,330	880
D	10,400	840
E	8,950	1,200
Total	30,630	3,820

*Based on terrestial environment. To convert to actual lunar suit time, it is recommended that values shown be multiplied by a "K" factor of three, which increases the total man-hours to 38,270.

elapsed time would be required for the extended exploration phase, assuming continuous lunar surface operation. With a reasonable number of repetitions assumed for various experiments, the experiments activity foreseen for extended lunar operations appears to be reasonable and is compatible with the general system capabilities foreseen.

Early exploration phases are sensitive to man-hour requirements and lunar surface stay time. Approximately one-tenth of the total man-hours (for a single performance of each experiment of the total program of experiments) is involved in the early phase of lunar exploration (Phases A and B). If it is conservatively assumed that there will be an average of three repetitions of each experiment and that there will be two men on the lunar surface, approximately 550 Earth days will be required to complete all of the experiments of Phases A and B at a lunar suit "K" factor of 1.0. This is equivalent to 40 missions with a lunar surface stay time capability of 14 days and assuming that each of the two astronauts works eight hours per day, of which only a fraction, 31 percent for Phases A and B, is in a spacesuit. The number of lunar missions for various lunar surface stay times is shown in Table 4 for lunar suit "K" factors of 1, 2, and 3.

Table 4 illustrates the strong sensitivity of mission duration capability on lunar suit capabilities. The major factor which can significantly reduce these effects is the future emphasis on experiment integration and consideration of greater automation and remote control.

Table 4. Number of Missions for Various Mission Durations

Mission Duration Capability (days)	Suit K Factor = 1.0	Suit K Factor = 2.0	Suit K Factor = 3.0
14	40	52	64
30	17	22	27
90	7	8	10

2.10 EARTH-BASED SCIENTIFIC SUPPORT REQUIREMENTS

A brief investigation was performed to determine possible requirements for Earth-based scientific support of lunar missions. The results of this study indicated that the most critical problem can be the lack of scientists for analysis of Earth return data. Three types of support were investigated: scientific analysis, technician requirements in support of the scientists, and laboratory facilities. Sensitivity analysis indicated that the demand for scientists is the most critical area because of the relatively long lead time required for training qualified scientists. The demand for technicians and laboratory facilities is dependent upon the availability of the scientists. A deficiency of approximately 9,000 man-years of scientific work is forecast to be accrued by the end of Phase C, which may be considered the transition phase between early and extended lunar exploration. The analysis and estimates are necessarily based on predictions of the scope of lunar exploration activities over the next decade, which is influenced by outside factors related to the lunar exploration program in terms of the funds available for lunar exploration.

3.0 CONCLUSIONS AND RECOMMENDATIONS

The study of Scientific Mission Support for Extended Lunar Exploration produced several results from which specific conclusions and recommendations can be drawn.

3.1 FUNDAMENTAL INVESTIGATIONS

A typical spectrum of 235 experiments was compiled under the category, "Fundamental Investigations." This compilation provides adequate coverage of scientific mission support requirements for mission planning purposes.

It is recommended that the lunar scientific program be integrated with planetary exploration.

3.2 MISSION SUPPORT AND MISCELLANEOUS BASIC AND APPLIED RESEARCH INVESTIGATIONS

A total of 105 experiments have been defined under the categories, "Mission Support Investigations" and "Miscellaneous Basic and Applied Research". These experiments have been defined in a preliminary manner. Of these experiments, 59 were considered top priority.

The results from this study indicate that more effort is justified to identify additional experiments and to delineate support requirements to a comparable degree with the fundamental experiments because significant mass and man-hours are involved. Any assessment of future system capability will be seriously impaired without a better accountability of applied science and engineering technology requirements. Accordingly, it is recommended that additional considerations be given to an overall integrated applied science and technology space experimental program for lunar and planetary exploration, as well as Earth-orbital operations.

3.3 EXPERIMENT SUPPORT REQUIREMENTS - EXPERIMENT DATA MANAGEMENT SYSTEM

Experiment support requirements were defined to a degree which will allow adequate estimation of subsystem requirements for present and immediate future mission planning and systems concept studies. An experiment data management system was formulated for compiling and displaying experiment and equipment data and mission support requirements. This system is flexible, simple to use, and has a large capacity for data storage.

The present data management system should be expanded to cover specific subsystem requirements in more detail. The capability for telemetry has already been incorporated in the present program; however, equally critical requirements in the near future may involve environmental control and life support subsystems and requirements for the suited astronaut. The experiment data management system should also be normalized to accommodate planetary exploration as well as Earth-orbital scientific operations.

3.4 LUNAR ASTRONAUT CAPABILITY

Capabilities of the suited astronaut in the lunar environment were studied to determine the influence or constraints that may affect the performance of the experiments. With the data available, it appears that the present rate of lunar suit development is not adequate. Lunar surface scientific operations will be seriously constrained by the limited capabilities of a man in a lunar suit. The types of work which will be required of the suited astronaut must be studied in much greater detail to obtain more realistic estimates of average task time. The following relationships must be determined:

1. The ratio of lunar to terrestrial task accomplishment times
2. The ratio of lunar to terrestrial operator work efficiencies
3. The ratio of lunar to terrestrial operator capabilities, with reference to force and work producing capability
4. The physiological cost of work in these environments, as modified by the nature of the suit, availability and nature of bracing/restraint devices, breathing gas mixtures, special tools, terrain, and other environmental considerations.

"Operations-oriented" scientists, as well as those primarily interested in the scientific data return, will be required to perform these studies. A greater use of automated procedures and remote control should be considered to reduce the required movement of the suited astronaut, to enable the performance of many more experiments for a given amount of time and to take advantage of man's most important functions of controlling, monitoring, and observing.

3.5 MOBILITY IMPLICATIONS

Apparent constraints of the lunar suit place more emphasis on the need for a short-range or LSSM-type vehicle for local mobility. Special emphasis should be placed on the integration of the suited man and the vehicle to enhance man's capability to perform experiments while remaining on the vehicle. Specifically, man should be seated on the vehicle in such a way that he is in immediate proximity to the lunar surface, with full visibility. Further, he should be able to perform lunar surface experiments while remaining seated on the vehicle.

A long-range roving vehicle will be needed to provide the integration of detailed local surface studies and information obtained from orbital vehicles and probes in order to present a total overall picture of the lunar surface geology and physical environment.

Flying vehicles should also be considered as means to accomplish lunar exploration objectives. At the present time, there appears to be no other transportation method available for reaching some of the otherwise inaccessible areas or points of maximum interest to the geoscientist.

3.6 LUNAR SURFACE EMPLACEMENT OF SCIENTIFIC OBSERVATORIES

The studies conducted on the large radio and optical astronomy observatory facilities indicate their feasibility, from an operational standpoint, during the intermediate phases of extended lunar exploration. This verifies, in a preliminary manner, the operational feasibility of performing major astronomy experiments during extended lunar exploration phases.

3.7 EXPLORATION PHASING

Based on experiment support requirements and sequencing studies, five logical phases of lunar scientific exploration have been identified. Phase A was considered to be the period of initial lunar landings. Phase B is generally compatible with the system capabilities of the present AAP concept and is defined as early lunar exploration. Phase C may more properly be classified as a transition period between early and extended lunar exploration phases. Phases C, D, and E are applicable to extended lunar exploration.

3.8 EARTH-BASED SCIENTIFIC SUPPORT REQUIREMENTS

The most critical problem will be the lack of a sufficient number of scientists for analysis of earth return data. A deficiency of 9,000 man-years of effort is predicted by conservative analysis during the intermediate phases of lunar exploration.

Further studies should be conducted in this area after the conclusion of the present studies with improved scientific mission and system capability information. However, the present results are sufficient to indicate that a very real problem exists, which warrants immediate attention.

4.0 INVESTIGATION AND EXPERIMENT SUMMARY

4.1 FUNDAMENTAL INVESTIGATIONS SUMMARY

In the course of this study, potential experiments were initially screened from the NASA source documentation (see Section 8.0, Volume 3) and grouped into investigations which attempt to answer 33 fundamental questions representing scientific guidelines. These fundamental questions were taken directly from the report of the National Academy of Sciences entitled, "Space Research - Directions for the Future." Fifteen of these questions are lunar-oriented. The remaining 18 questions are space-oriented and have been derived from the same report, considering the Moon as a platform to enhance the exploration of the universe. The investigations corresponding to the 10 discipline areas are correlated with the 33 fundamental questions in Figure 3. The purpose of this correlation is to indicate the relative contribution of each of the proposed investigations to providing an answer to each of the fundamental questions. The fundamental questions are listed in an abbreviated form across the top of each matrix. The investigations are listed in the left-hand matrix column.

Geodesy, Geology, and Geochemistry investigations attempt mainly to answer specific lunar-oriented questions. The Geophysics investigations are concentrated on questions 1 to 15 on lunar exploration and columns 31 and 32, which are questions concerning terrestrial and planetary geophysics. The Particles and Fields investigations are primarily directed toward questions relating to radiation history and cosmic ray intensity at the Moon, solar phenomena (flares, sunspots, solar wind, etc.), and the interactions of the geomagnetosphere with the solar wind and the solar and galactic particles. The Lunar Atmospheres, Biology, and Astronomy investigations provide a widely scattered correlation with the fundamental questions. These five matrices cannot be compared with each other. Only the integrated contribution to answering the NAS fundamental questions by the investigations compiled in this study can be assessed.

These matrices indicate there is coverage of all the scientific questions. The actual extent of the coverage can, however, be determined only by detailed examination of the actual experiments. Mission Support and Miscellaneous Basic and Applied Research investigations are included because they are, in many cases, key experiments and contribute in an indirect manner.

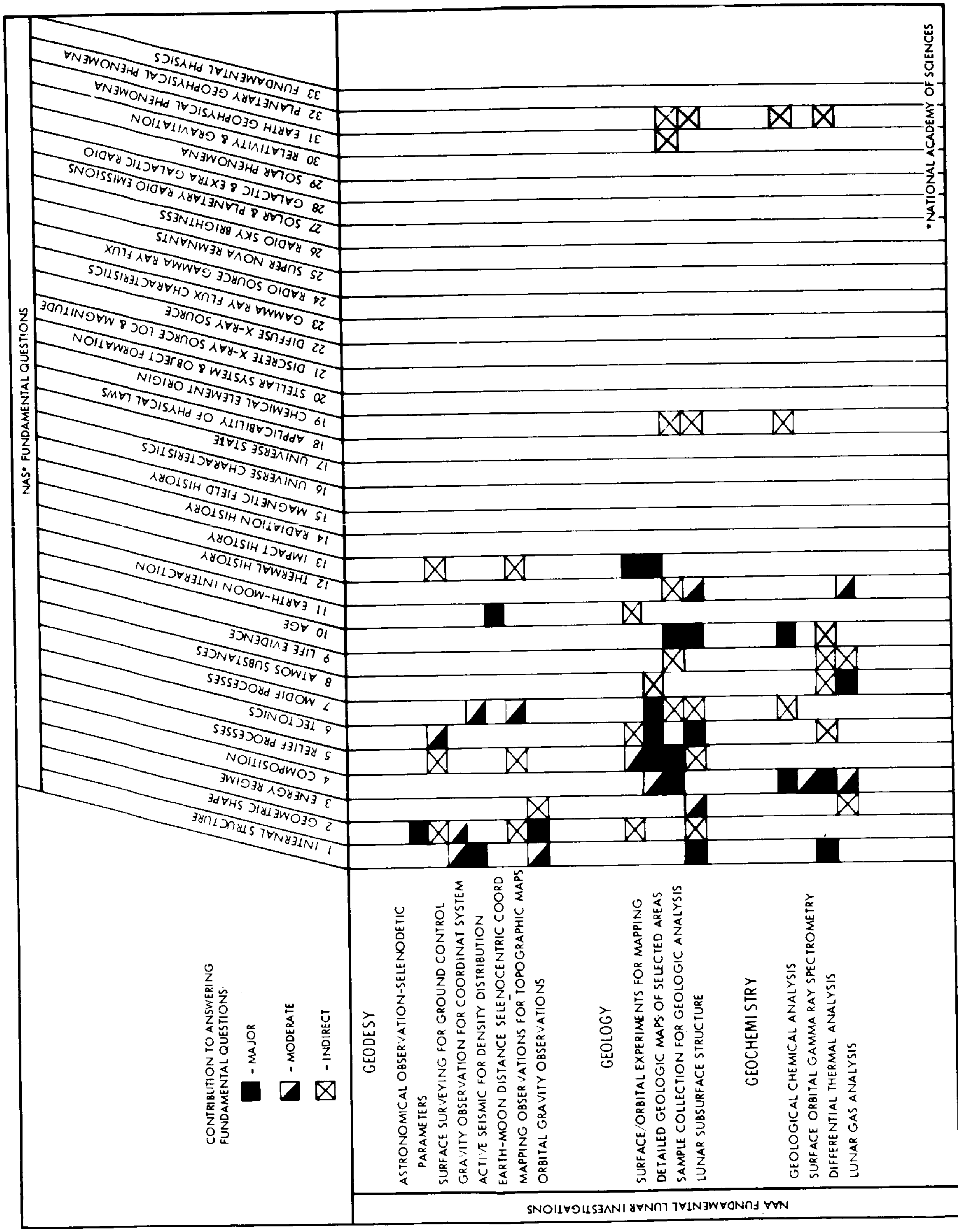

Figure 3a. Correlation of Fundamental Investigations With Fundamental Questions Raised by the Space Science Board, National Academy of Sciences

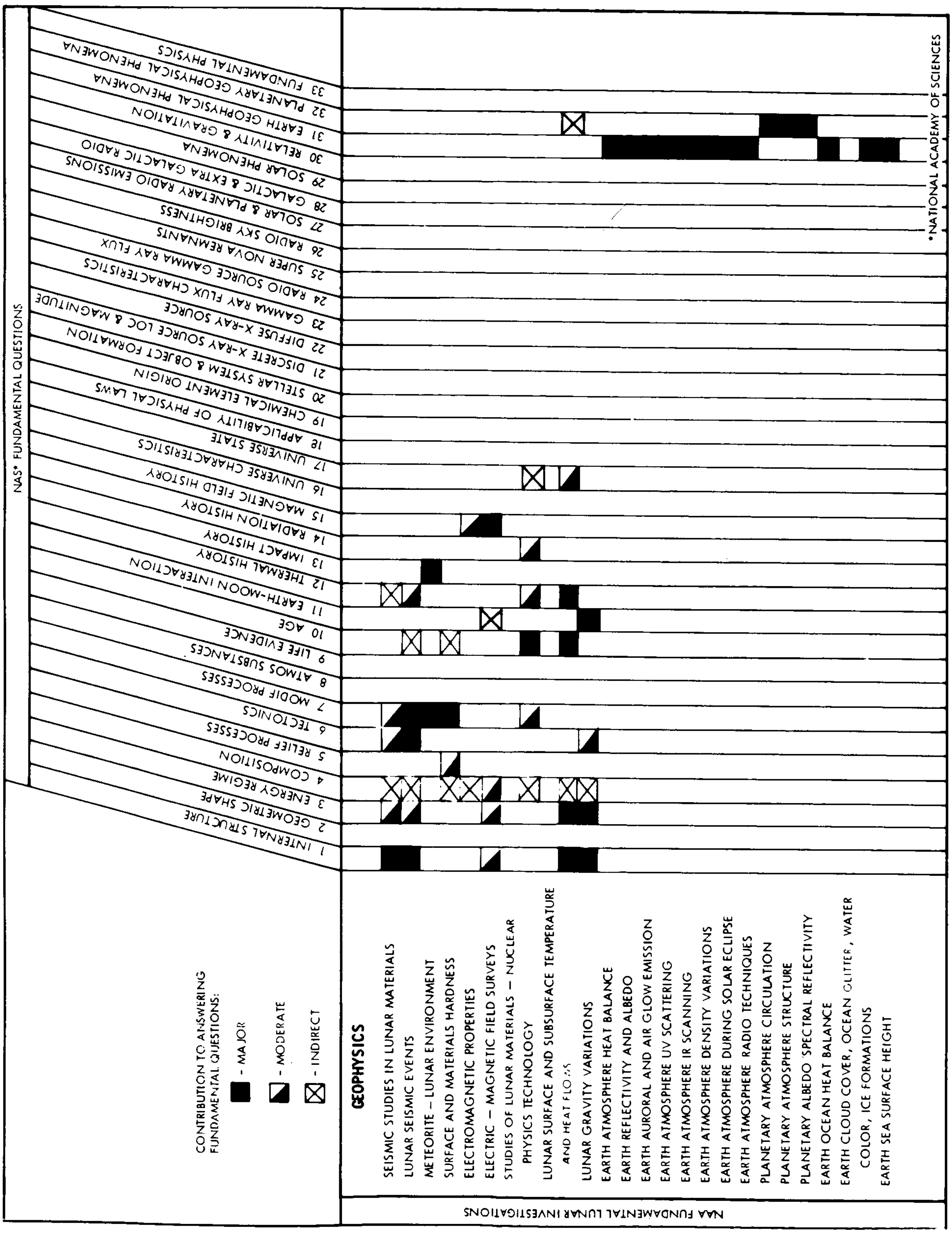

Figure 3a. Correlation of Fundamental Investigations With Fundamental Questions Raised by the Space Science Board, National Academy of Sciences (Cont)

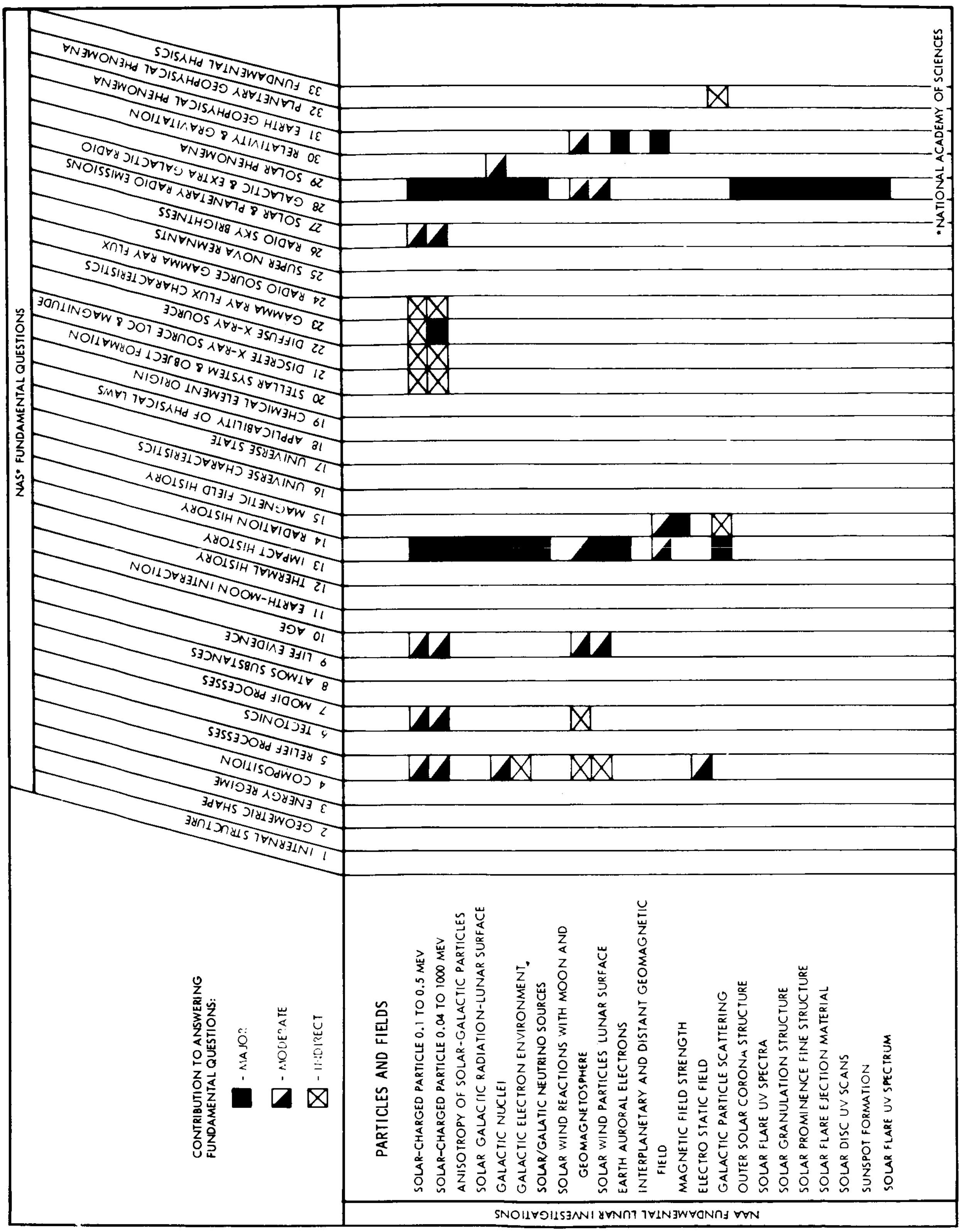

Figure 3a. Correlation of Fundamental Investigations With Fundamental Questions Raised by the Space Science Board, National Academy of Sciences (Cont)

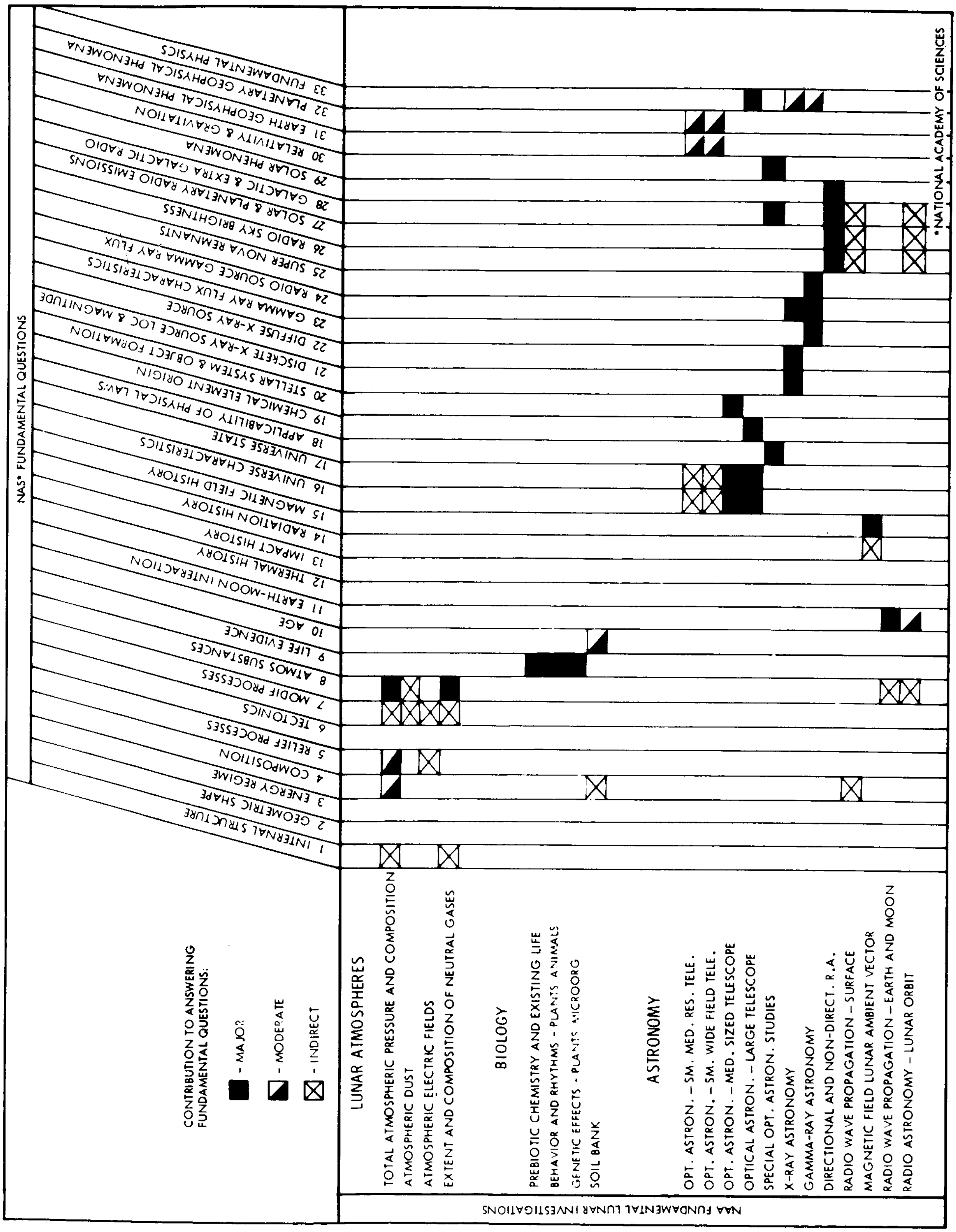

Figure 3a. Correlation of Fundamental Investigations With Fundamental Questions Raised by the Space Science Board, National Academy of Sciences (Cont)

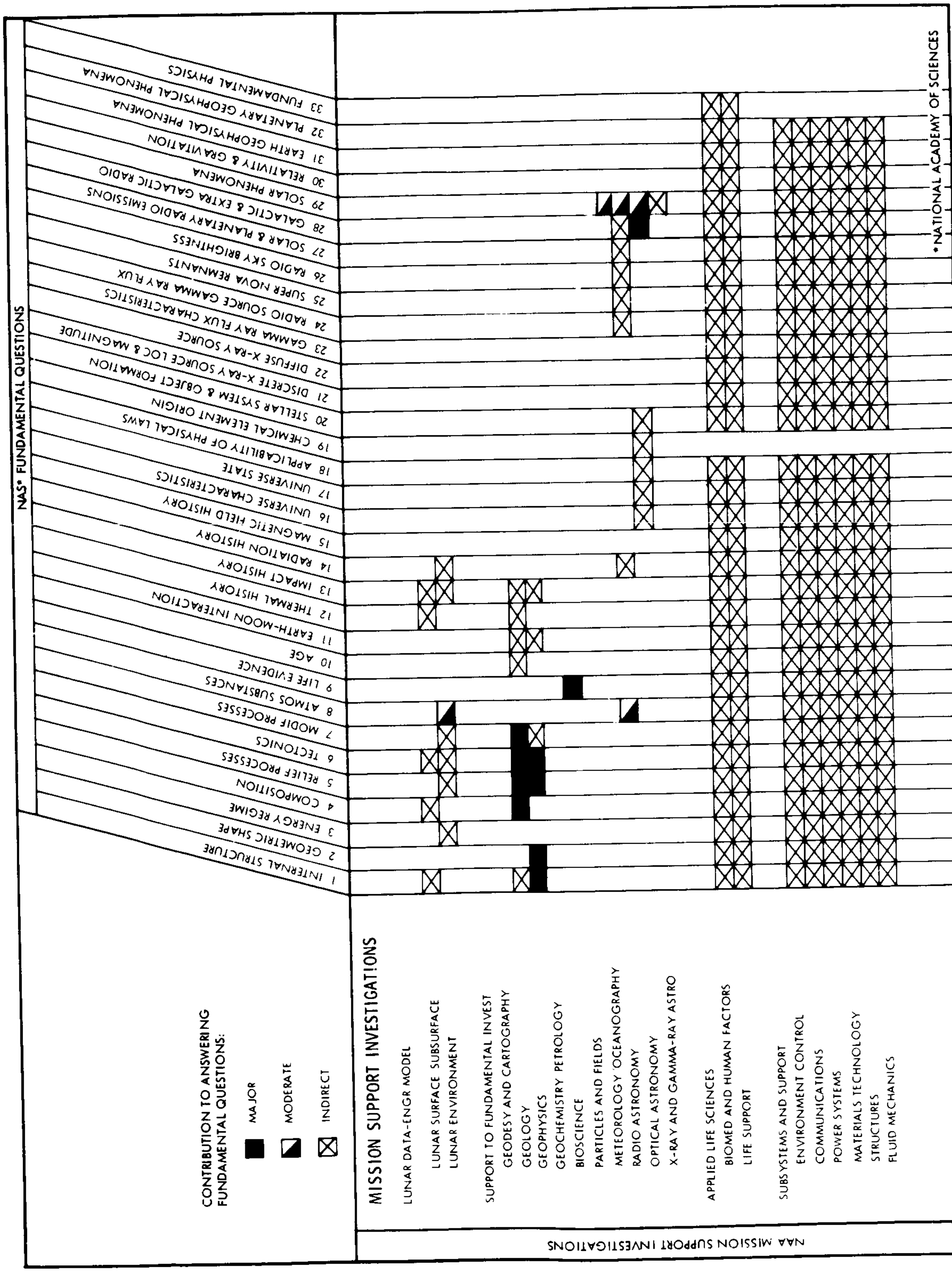

Figure 3b. Correlation of Mission Support Investigations With Fundamental Questions Raised by the Space Science Board, National Academy of Sciences

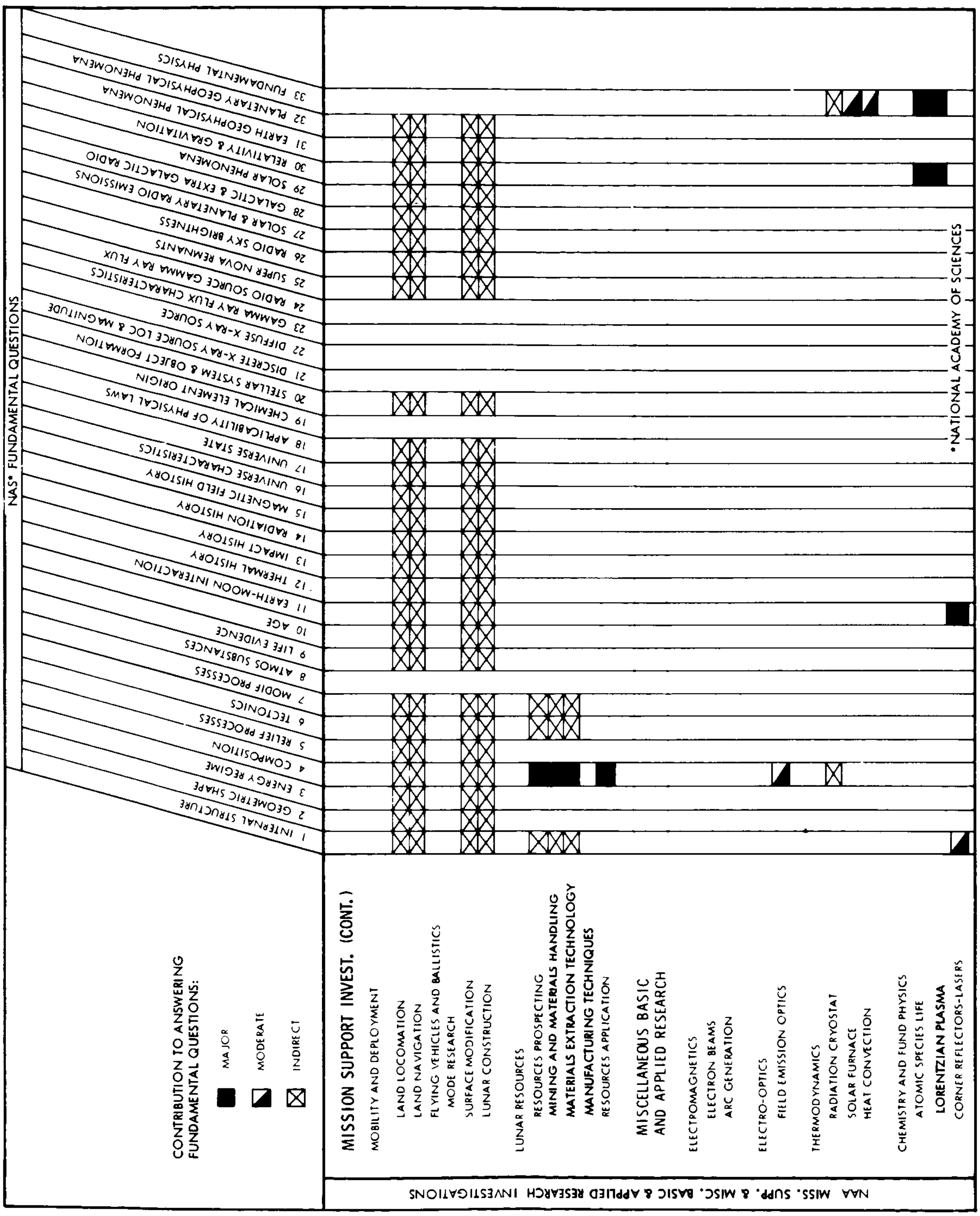

Figure 3c. Correlation of Mission Support and Miscellaneous Basic and Applied Research Investigations With Fundamental Questions Raised by the Space Science Board, National Academy of Sciences

In view of the large number of experiments (235) which comprise the category, "Fundamental Investigations," it is not possible to give a detailed description of the experiments in this summary volume; therefore, only the investigations and typical examples of the experiments will be discussed below. A full description can be found in Volume 5, Appendix B, of this report.

4.1.1 Lunar Atmospheres

The Lunar Atmospheres investigations contain experiments to determine:

Total atmospheric pressure

Composition of lunar atmospheres

Atmospheric variations over the lunar surface

Extent and composition of neutral gases emanating from the lunar surface

It should be noted here that under the Lunar Atmospheres investigation, "Determination of Total Lunar Pressure," the objectives for the two atmospheric pressure experiments shown are the same. However, major differences are present between the two experiments which require their identification as separate experiments. Due primarily to the later time phase assumed, a greater refinement in instrumentation technology and mobility is feasible for the latter experiment; hence, measurements at more distant sites from the vicinity of landing sites are feasible. A better defined picture of the total lunar atmosphere as opposed to anomalous or contaminated atmosphere is possible. The preceding example indicates the value of predetermining experimental programs across several experiments.

4.1.2 Geodesy

In Geodesy, a comprehensive program is implied, involving precision orbital mapping and distance determinations as well as access to seismic and gravity potential data. The Geodesy investigations are as follows:

Astronomical observations used to determine geodetic (selenodetic) parameters

Geodetic surface surveying observations to establish ground control for lunar orbital mapping

Lunar surface gravity observations to aid in determining an accurate geodetic coordinate system

Active seismic measurements to determine material density distributions to supplement surface gravity observations

Earth-Moon distance observations to aid in establishing accurate selenocentric coordinate systems and to facilitate transformation between geocentric and selenocentric coordinate systems

Geodetic mapping observations to provide data for detailed topographic maps of the Moon

Gravity observations performed from lunar orbit to supplement surface gravity and seismic data

"Selenodetic Mapping Observations from Orbit" is a typical investigation intended to provide data for detailed topographic lunar maps. This investigation has a single experiment aimed essentially at providing stereo coverage of lunar landing sites to a 1-meter relative and 10-meter absolute accuracy for base map purposes. This requirement involves selenodetic mapping with LEM and Apollo command module vehicles to provide stereophotography coverage from which topography maps will be prepared for selected lunar areas.

4.1.3 Geology

The Geology investigations consist of the following activities:

Production of lunar geologic maps from lunar orbit data. Surface experiments will be utilized to augment data obtained from orbit

Construction of detailed geologic maps of selected lunar areas

Lunar sample collection for geological analysis (analyses to be performed either at lunar base or on Earth)

Determination of subsurface structure of the lunar body

To further illustrate the scope of the geoscience investigations and their interrelationships across discipline areas, Geology will directly rely on the selenodesy-cartography investigations previously cited to obtain the data for map preparation and photogeologies interpretation. "Production of Lunar Geologic Maps from Lunar Orbit Data" demonstrates that the immediately preceding experiment, concerning topographic map preparation from the selenodesy-cartography investigation, had direct application to the geologic mapping effort delineated under the first two geology investigations. Data from the geodesy investigations would be provided for this use.

4.1.4 Geochemistry

Under Geochemistry, investigations will complement the preceding disciplinary studies by providing detailed chemical analysis of lunar materials and gases associated with features such as fumaroles. Such studies can also provide the means for comparison of a time scale of lunar events with that established for Earth history. Geochemical investigations include:

Chemical analysis to determine the geochemical, petrological, and mineralogical nature of lunar materials

Gamma-ray spectrometry experiments on surface traverses and from lunar orbit to provide direct information on radio-nuclides present on the lunar surface

Differential thermal analysis investigation in which volatiles from lunar materials are distilled and collected for further analysis of composition

Chemical analyses of lunar gases by use of mass spectrometers

A typical geochemical investigation is composed of experiments involving gamma-ray spectrometry, which is concerned with the determination of unique gamma-ray spectral signatures associated with radioisotopes of interest. Due to the absence of a lunar atmosphere, it should be possible to recognize these gamma-ray spectra from orbit as well. It will be possible to provide a chemical analysis of surface and near-surface materials without recourse to an external energy mechanism such as is required for neutron and gamma-ray activation surveys. This experiment is based entirely on classification by natural radioactivity of the materials encountered on traverse.

4.1.5 Geophysics

The largest number of investigations are contained in the Geophysics discipline area. Several instrumental techniques are encompassed, although these are primarily concerned with the study of the properties of lunar bodies. The latter portion of the investigations are concerned with Earth monitoring from the lunar surface. These are of understandably lower priority in view of the fact that these investigations could well be satisfied by Earth orbital experiments. In this sense, they are "targets of opportunity" and may be performed if time allows. In addition, planetary geophysics investigations are included.

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The Geophysics investigations are:

Seismic studies on lunar materials

Lunar seismic events

Surveys of meteorites in the lunar environment

Lunar surface and material hardness

Electromagnetic properties of the lunar material

Electric and magnetic field surveys

Studies of lunar materials with nuclear physics techniques

Lunar surface and subsurface temperatures and heat flows

Variations in lunar gravity

Studies of heat balance of Earth's atmosphere from the lunar landing site

Studies of Earth's reflectivity and albedo from the lunar landing site

Studies of Earth's auroral and air glow emissions

Studies of ultraviolet scattering in Earth's atmosphere

Studies of Earth's atmosphere by passive infrared scanning

Studies of Earth's upper atmosphere density variations by stellar refraction techniques

Studies of Earth's atmosphere during terrestrial eclipse of the Sun

Studies of Earth's atmosphere by use of radio telescope techniques

Studies of nonterrestrial planetary atmosphere circulations

Studies of temperatures and composition of planetary atmospheres

Determination of planetary albedos and spectral reflectivities

Studies of the Earth's ocean heat balance from the lunar base

Studies of Earth's cloud cover, sea surface glitter, water color, ice formation, and other gross dynamic patterns by use of sequential multiband photography

Studies of feasibility of Earth-sea-surface height measurements from the lunar base by use of laser ranging devices or other techniques

A typical geophysics investigation is the "Lunar Seismic Event Studies and Tectonic Measurements," which is the most fundamental to determining the internal structure and environment of the Moon. The structure of the interior of the Earth has been primarily determined by seismic techniques that monitor the energy transmitted through the Earth by strong earthquakes. Earth models are based on studies of the presence or absence of the various P, S, and L waves and their respective arrival times; hence, by analogy, this experiment has great significance for determination of the lunar interior. Additionally, it has great significance to problems of internal thermal and electrical conductivity structures since it may serve as an initial basis for modeling the interior of the Moon.

A typical experiment within the preceding geophysics investigation is "Seismic Recording - Passive - Large Array" which is designed for a later phase of lunar experiments for which regions of potential tectonic activity have been identified. The experiment requires establishment of a network of seismic stations with sufficient coverage to permit definition of a shadow zone due to screening of seismic shear waves by a liquid lunar core (if present). Simultaneous studies of possible crustal or mantel characteristics would result from studies of reflected and refracted P and S waves from lunar seismic events.

Studies of the deep interior by explosive techniques do not seem to be feasible since with Earth signal-to-noise ratios, several kilotons of high explosives are required to simulate earthquakes of 4 to 5 magnitude (Richter scale). Smaller energies could not penetrate the body of the Moon. Coupled with the seismic measurements would be a series of precision optical distance measurements to fractional centimeter accuracy. Routine measurements would be made across known faults to determine crustal motion and strain accumulation. At the time of the major seismic events with epicenters in the measurement region, special measurements would be made to determine rates of motion along the associated faults.

4.1.6 Particles and Fields

The present and prolonged past exposure of the lunar surface to energetic ionizing particulate radiation provides valuable and sometimes unique opportunities to study the current and historical levels of the radiation environment. A lunar exploration objective realized through investigations based on measurements with particle detectors and spectrometers is the evaluation of the energy spectra of protons, electrons, and heavy nuclei associated with solar activity and galactic sources. Evaluation of secular trends in the past radiation level requires geochemical techniques similar to those used in determination of crystalline structure and radioactivity of subsurface materials.

The Moon also represents an obstruction to the solar wind, larger than the mean free paths, Debye length and Larmor radii of solar wind particles, and lacking a strong intrinsic magnetic field. Unique investigations in the magneto-hydrodynamics of the interplanetary medium can, therefore, be conducted at and above the lunar surface. Particles and Fields investigations, including solar physics, are:

Studies of solar-charged particle environment at the lunar surface, 0.1 to 0.5 Mev energy range

Studies of solar-charged particle environment at the lunar surface in the 0.04 to 1000 Mev energy range

Studies of anisotropy versus charge and energy of solar and galactic particles

Studies of solar and galactic radiation environment at lunar surface. Also includes solar energetic electrons associated with solar flares.

Studies of galactic nuclei environment at the lunar surface, 100 Mev to 100+ Bev energy range

Studies of galactic electron environment at the lunar surface, 100 to 1000 Mev energies

Studies of solar and galactic neutrino sources

Studies of solar wind interactions with Moon and geomagnetosphere, including the magneto-hydrodynamics of the solar wind flow past the Earth and Moon

Studies of solar wind particles at the lunar surface and near the Moon

Studies of electrons escaping the Earth auroral zones during geomagnetic storms

Studies of the interplanetary magnetic field and the distant geomagnetic field

Studies of the magnetic field strength and time variations at the lunar surface and near the Moon

Studies of the electrostatic field at and near the lunar surface

Studies of galactic particle scattering and reactions

Studies of the outer solar corona structure

Studies of solar flare UV spectra

Studies of solar granulation structure and granulation velocity field

Studies of solar prominence fine structure

Studies of solar flare ejection of material

Moderate dispersion UV scans over the solar disk

Studies of the UV spectrum of solar flares

Studies of sunspot formation and development

A typical example of a Particles and Fields investigation is the "Solar Wind Particles At and Near Surface" investigation. This investigation encompasses four experiments: two experiments measure the charged particle energy spectrum versus height from 0 to 10 meters and from 0 to 100 meters above the lunar surface; two other experiments measure the charged particle spectrum versus Sun position at sunrise, noon, and midnight and also in the antisolar tail of the geomagnetosphere.

Other investigations include particulate radiation at the lunar surface, which includes particles above 10^5 Mev, the highest energies realizable by presently planned accelerators. Fundamental particle physics can benefit from the presence of this radiation in the natural lunar vacuum. Using the stable lunar surface as an optical bench, long flight paths can be set up to observe; i.e., proton-proton scattering at small angles and baryon decay branching ratios.

The perfect visibility, stability, and complete atmospheric transparency which the Moon provides in astronomical investigations also permits major advances in solar physics, including the investigation by astronomical techniques of the structure, and behavior of active solar phenomena. The composition and structure of all visible levels of the solar atmosphere can also be explored with enhanced angular resolution.

4.1.7 Biology

The question of life on the Moon, at first consideration a most remote possibility, requires highly important lunar exploration investigations when it is broadened to include extremely primitive and extinct life forms. Evidence of prebiotic chemicals is also of great interest. Another question in lunar biology is the possible future development of life. Investigations formulated for biology include:

> Studies of prebiotic chemistry and evidence of existing life in lunar materials
>
> Studies of the behavior and rhythms of plants for several generations in the lunar environment
>
> Studies of the behavior and rhythms of animals for several generations in the lunar environment
>
> Genetic effects of lunar conditions and Earth-Moon trips on plants
>
> Genetic effects of lunar conditions and Earth-Moon trips on microorganisms
>
> Establishment of a lunar soil bank at an early period of lunar exploration for use in later experiments

Evaluation of the response of terrestrial biological organisms to the lunar environment will provide fundamental knowledge in genetics and growth processes and also provide insight to the suitability of the Moon for the development of life. Investigations in this area include the behavior and rhythmic cycles of plants and animals (including man), and the genetic effects of such lunar environmental factors as ionizing radiation.

Biological contamination of the Moon is a problem intimately related to the search for life forms. Early lunar exploration vehicles, whether manned or unmanned, may introduce contaminants that will possibly be altered by radiation to unrecognizable forms by the time of advanced exploration missions. Therefore, investigations utilizing soil banks are very important.

An investigation to search for existing life or evidence of prebiotic chemical activity consists of experiments involving techniques of collection and preparation of uncontaminated samples of lunar materials, qualitative analysis of organic chemicals in the samples, and measurements of reproductive and metabolic processes. Metabolic analysis includes measurement (on the Moon and on Earth) of electrical conductivity, optical activity, gas exchange rates, and heat production rates.

4.1.8 Astronomy

The use of the Moon as an astronomical observatory platform will be desirable to augment Earth and Earth-orbital observations. The minimum size telescope to perform observations of scientific significance will be on the order of 30- to 40-inch apertures, while a larger telescope, on the order of 100-inch aperture, is extremely desirable. Investigations formulated for astronomy are:

Optical astronomy experiments based on the use of a small, medium-resolution reflecting telescope. The experiments include testing of the lunar environment for development of an astronomical observatory.

Optical astronomy experiments based on the use of a small, medium-resolution reflecting telescope for medium-resolution photos of planets and stars, photoelectric studies, and medium dispersion spectroscopic studies.

Optical astronomy experiments based on the use of a small, wide-field reflecting telescope with a five-degree field of view. These experiments include photographic sky surveys at a variety of wavelengths, studies of extended surface phenomena such as zodiacal light, gegenschein, lunar libration clouds, and scanning photometer studies.

Optical astronomy experiments based on the use of a medium-sized reflecting telescope. These studies will include photographs of faint and bright galaxies, nebulae, etc., at a variety of wavelengths, photoelectric photometry at wavelengths inaccessible from Earth's surface, and spectroscopic studies at low, medium, and high dispersion.

Optical astronomy experiments based on the use of a large diffraction-limited telescope, with major operations in the wavelength interval of 1000 to 3000 angstroms. The experiments will include very high-resolution photography, high-dispersion spectroscopy, systematic studies of outer envelopes of stars, surveys to detect planet-like companions of stars, and systematic studies of high-energy phenomena in stars and quasars.

Special optical astronomy studies, such as the Lyman-Alpha survey of the sky or Einstein eclipse problem.

X-ray astronomic observations of the X-ray radiation from the Sun, stars, galaxies, or other X-ray sources.

Gamma-ray astronomic observations

Nondirectional radio astronomy

Directional radio astronomy

Submillimeter radio astronomy

Studies of radio wave propagation between stations on the lunar surface

Studies of variations of the lunar ambient vector magnetic field

Studies of radio wave propagation between the Earth and Moon, at various frequencies, polarizations, etc.

Measurements of radio astronomy interest performed from lunar orbit, such as electric field measurements, magnetic field measurements, and particle flux measurements

While it is certain that many unique astronomical observations can be conducted with even a small telescope on the lunar surface, full exploitation of the astronomical potential of the Moon requires evaluation of the Moon as a major observatory site. Seismic stability, soil bearing strength, thermal stresses, meteoroid and radiation damage, and techniques of assembling and using a large telescope in the lunar environment must be assessed. A small (12-inch) telescope will contribute here as well as in direct observational investigations such as UV sky survey.

The investigation of all classes of celestial objects, especially at wavelengths to which the Earth's atmosphere is opaque, is a central objective of space astronomy, fulfilled through investigations with larger telescopes which take advantage of a natural stable platform in a vacuum. The vast number of individual observations can be illustrated by an experiment involving high-resolution photography in the visible and UV with a 40-inch telescope. The observations concern star densities near the centers of dense clusters such as M31 (Hercules). A similar experiment is directed toward the magnitude versus spectral class distribution of individual stars in galaxies, with consequent refinement of the cosmic distance scale.

Astronomical observations which benefit greatly from performance on the Moon are those that test basic scientific hypotheses. For example, galactic recession velocities at great distances can be determined from spectral shifts into the far infrared and highly precise measurements of the bending of light in the solar gravitational field can be made.

The establishment of a radio astronomical observatory in the quiet of the lunar far side appears to be a task for the 1980's. Criteria for such a facility can be developed during the 1970's, however, by measuring the ac resistivity and dielectric constant of surface and subsurface materials, and the plasma frequencies of the lunar atmosphere and the cislunar medium and by performing many smaller experiments that will return significant scientific data.

4.2 MISSION SUPPORT INVESTIGATIONS

4.2.1 Surface and Environment Engineering Properties

Lunar surface and subsurface properties and environment characteristics relate to additional acquisition of data beyond that obtained in the Fundamental Experiments, which will aid the development of a lunar engineering model. These characteristics are very important to the determination of engineering design and operations criteria, both for fundamental science and technology support. It is expected that the Fundamental Experiments will contribute much data directly applicable to engineering models. Consequently, experiments included within these mission support discipline areas are those that augment the fundamental studies to provide a more complete model which fulfills mission and system implementation data needs.

A brief reference to a typical experiment that relates to each type of data need is presented here to illustrate the composition of these areas. An orbital experiment entitled "Topography of Proposed AAP LEM Landing Sites" provides vital macroscopic characteristics data for mission support. An experiment entitled "Surface and Subsurface Electrical Parameters" provides information for application to radio astronomy and communications experiments. Under "Chemical Properties," an experiment entitled "Corrosive Action of Lunar Soils" provides model surface data affecting instruments, transmission lines, and radiators. "Seismic Environment" is a monitoring-type experiment which supports the location and operation of an astronomical observatory.

In the general area of "Surface Environmental Data," the experiment, "Lunar Surface Dust Environment," provides a routine program of monitoring the accumulation of dust deposited during lunar operations.

Another experiment entitled "Lunar RF Noise" consists of two parts: one measures noise at low frequencies in support of radio astronomy, and another measures noise at higher frequencies in support of lunar communications. A lunar atmospheric investigation which is complementary to fundamental studies is entitled "Effects of Leakage From Vehicles, Shelters, and Spacesuits."

4.2.2 Support to Fundamental Investigations

A basic objective of mission support is to contribute to the effectiveness of fundamental scientific investigations. Most of these experiments are considered very important to the fundamental program and should be performed during early exploration. Discipline areas supported are Geology, Geophysics, Geochemistry, Biology, and Astronomy.

A typical experiment which is related to experiment-environment investigations is entitled "Lunar Drill Bit Technology." This experiment provides an assessment of designs and techniques for core drilling in differing lunar lithologies. The "Relative Electrode Electrical Coupling Properties" experiment provides contact data necessary for correct determination of resistivity data used in deducing subsurface anomalies. Another experiment which yields vital experiment-environment interface data is entitled "Explosive Energy Coupling in Lunar Materials" and is basic to all active seismic studies.

Correlative information is obtained typically from the "Sampling Survey Techniques" experiment, which is directed toward maximizing the information value from collected samples. "Calibration of Remote Sensing Techniques" involves correlation of information on traverses, and validation of map data.

Experiments which establish the validity of results from fundamental studies are typified by the "Biological Contamination of Lunar Soil" experiment which determines the degree to which the Moon or samples can be contaminated and provides an extraterrestrial assessment of a planetary life detection experiment package. A second validating type of experiment is the "Lunar Geological-Geochemical Sample Cassettes" experiment which evaluates techniques for preservation of samples for delivery to Earth in their original state.

The "Lunar Optical Astronomy Test Program" experiment investigates the practical problems of operating a 12-inch telescope in the lunar environment. Experimental data desired include pointing accuracy, changes in alignment introduced by thermal and possible seismic phenomena, and effects of the meteoritic and dust environment. The "Dielectric Properties of the

Lunar Sphere" experiment is an orbital experiment which provides information on the listening environment of the lunar backside for application to radio astronomy program planning.

4.2.3 Supporting Technologies Investigations

The spectrum of technologies required to support extended exploration of the Moon is very broad. By organization, 18 technological fields have been defined within the supporting technology groupings. Experiments listed are typical examples that illustrate the composition of this major portion of lunar mission support.

The biomedical and human factors experiments are to ensure the safety and well-being of the astronauts, to provide quantitative assessments of man's capabilities and long-term adaptabilities to the lunar environment, and to provide an in-situ experimental basis for extending man's effectiveness. These investigations, in general, are rated as very important and they should be performed during early phases of the lunar exploration program. The "Work Capability Tests" identified as an illustrative human factors experiment defines force and other work limits that affect man's capability for performing useful work in the lunar environment.

Life support experiments are directed primarily to developing an advanced technology for closed ecology and to defining biological effects of exposure to lunar conditions. The "Use of Lunar Soils for Micro-organisms and Higher Plants" experiment examines the feasibility of treating and enriching lunar soils for application as growth media for higher plants and for micro-organisms of potential ecological interest.

The experiment, "Materials Research Technology," has general application to mission support. Within this investigational area, the experiment, "Elastomer and Polymer Behavior", determines the effects of the lunar environment on the properties of parts such as vacuum-joined elastomers and plastics, coated fabrics, spacesuits, hoses, and boots.

A range of supporting investigations are included within the system/subsystem technology grouping. These are environmental control, communications, power, materials research, structures, mobility technology (land locomotion and navigation), and deployment technology (surface modification and construction).

The experiment "RF Ground Wave Propagation" is an example of the technology advancements required within the basic subsystems grouping. This experiment measures near- and far-field strengths of lunar surface waves at several frequencies and distances to confirm the propagation model. It also leads to definition of the most effective link.

"Soil Value Variations in Lunar Terrain" is an experiment within the "Land Locomotion Research" investigation. This experiment envisions the use of a field Bevameter-type instrument to measure locomotive pressure-sinkage and draw bar-pull relationships in lunar terrain. Soil values are important in design and improvement of surface vehicles. Also, correlation of soil values variations with topography and lithology will support the planning of traverse routes. "Metal Joining Techniques in Lunar Construction" provides an assessment of welding, brazing, and diffusion bonding processes in construction and repair.

Resources utilization feasibility includes lunar resources prospecting and analysis, mining and materials handling technology, minerals extraction and processing technology, and resources application techniques. Early investigations within the "Resources Utilization Feasibility" functional grouping (see Table 2) will be concerned primarily with determination of the availability of usable materials. "Lunar Dry Cement and Concrete Applications" is an experiment more suited to the later exploration. This experiment examines the utility of lunar materials as aggregates, fillers, and binders to produce a lunar equivalent of concrete, and is envisioned primarily as a series of field tests utilizing processes developed on Earth with returned lunar materials.

4.3 MISCELLANEOUS BASIC AND APPLIED RESEARCH

The lunar environment affords unique opportunities for investigations of fundamental scientific significance and for investigations that lead to improved technology for lunar, planetary exploration, and terrestrial applications. Further effort could be expected to define an expanded utility of the lunar environment and facilities for supporting basic and applied research.

Lunar environmental conditions advantageous to the performance of research are: (1) an extensive ultra-high vacuum; (2) a low-magnetic field environment; (3) unfiltered thermal energy from the Sun; (4) temperatures approaching absolute zero with proper design; (5) foundation stability for emplacement and alignment; and (6) potentially usable materials. Factors such as these can be utilized in basic research to permit the performance of experiments as in atomic physics, for example, where practical Earth laboratory limitations are restrictive or compromise results.

Concerning electromagnetics, the ability to generate high-intensity arcs, electron beams, and ion beams in the open (i.e., without a vacuum chamber) offers the possibility of advancing extraction, welding, and other materials processing techniques. These techniques are applicable to lunar materials operations and to lunar-based operations on terrestrial materials; they can also be extended to Earth-based fabrication processes.

An investigation entitled "Electron/Ion Field Emission Optics" takes advantage of the natural hard vacuum environment to photograph field emission patterns of elements and compounds, which leads to capabilities for analyzing lunar materials and performing atomic research.

Concerning thermodynamics, the "Radiation Cryostat" investigation provides for measurement of the thermal characteristics and assessment of the utility of a superinsulated cavity with a heat sink reflector facing space of low stellar intensity. Operation in the long lunar night and application to superconductivity studies are particularly interesting. The "Controllable Solar Furnace" investigation provides data for small scale experiments for application to large operational furnace arrays which are potentially applicable to materials research, construction, power generation, and resources extraction and processing. A third investigation determines flow parameters of heated gases at 1/6 g for correlation with 1-g and zero-g data.

Fundamental research in physics also benefits from the lunar environment. An example of this is measurement of the expansion of Lorentzian or collisionless plasmas produced by electrical or chemical explosions, and of fields in accompanying hydromagnetic shock waves. The "Atomic Species Lifetimes" investigation takes advantage of the extensive lunar vacuum to provide for measurement of the lifetimes of long-lived atomic species. This investigation requires a highly collimated beam traveling parallel to the lunar surface with stations out to many kilometers to measure decay of excitation and ionization states. The "Corner Reflectors for Laser Beams" investigation is an Earth-Moon investigation suggested by the National Research Council of the National Academy of Sciences. In addition to geodesy applications, investigations using the corner reflectors should provide refined data on the gravitational constant and may possibly yield data relating to gravity waves.

4.4 EXPERIMENT SUMMARY

Table 5 presents a summary of the experiments by discipline area which are presently included in the Experiment Data Management System. The experiments are identified by descriptive title, with a summary of major support parameters.

Certain experiments in the sequences have been footnoted because a support requirement (total power, for example) exceeded the recommended level for the particular exploration phase in which the experiment has been sequenced for accomplishment.* These experiments are candidates for certain packages or emplaced stations which were considered to be

*See Section 6.2.3

available for that particular phase as indicated in the following discussion and do not exceed the support capabilities presently envisioned for that particular package.

1. The ALSEP energy source was considered available in Phase A. For estimating purposes, this source was considered to be a RTG unit with a power output ranging between 56 and 65 watts supplied for a period of one year. Accordingly, on the basis of one year, the ALSEP energy source was estimated to provide a total energy ranging between 490 and 570 kilowatt hours.

2. The ESS energy source was considered available in Phase B and later. This source is presently envisioned as consisting of a 100-watt central station RTG and three 10-watt satellite station RTG units, all operative for a period of at least one year. Accordingly, on the basis of one year, the total energy supplied by the ESS source was estimated to range between 1100 and 1200 kilowatt hours.

3. The Astronaut Survey Staff was considered available during Phase A. A battery source is indicated for this instrument. The batteries would be recharged at the lunar base or batteries replaced, as applicable, to provide the estimated total power expenditure for this unit. Total mass listed for this experiment includes the mass of the TV monitor which is also used for other purposes.

4. An independent emplaced package for monitoring gas emissions from suspected sources was assumed available for Phase B. This package could be emplaced from a lunar orbiting satellite or from a traverse vehicle. The power source could be similar to that of the ALSEP.

Table 5. Experiment Summary Information (SMS-ELE)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watts)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
				LUNAR ATMOSPHERES								
01030159	Lunar atmospheric pressure at landing sites	Site	Walk	Initial landings	1	1.0	8,000*	0.1	20	$ 1,000,000 100,000	2	0
01030260	Time variations of lunar atmosphere pressure	Site	LSSM	Early exploration	1	1.0	40,000**	0.1	20	$ 1,000,000 100,000	2	0
02030263	Charged atmospheric dust analyses with a charged dust spectrometer	Site	Walk	Initial landings	1	8.5	2,000*	1.0	0.5	$ 3,000,000 300,000	3	0
02030361	Electric field magnitude and direction at and near lunar surface	Site	LSSM	Early exploration	1	2.0	0.016	1.0	0.4	$ 1,000,000 50,000	3	0
02030362	Electric field magnitude and direction at different lunar positions	Traverse	Rover	Extended exploration	1	2.0	0.016	0.1	0.4	$ 1,000,000 50,000	3	0
01030464	Gas chromatography for identification of heavy gases	Traverse	Rover	Extended exploration	1	6.3	18,000	20	30	$ 2,000,000 200,000	3	0
				SELENODESY (GEODESY)								
12020606	Selenodetic mapping to establish detailed topographic lunar maps	Orbit	None	Orbital	1	530	5,100	0	1,000	$ 10,000,000 1,000,000	5	100
11010101	Selenodetic astronomy observations for improving map accuracy	Site, traverse	Combinations of vehicles	All phases	1	150	6,800	120	0.25	$ 1,000,000 100,000	5	60
11010505	Earth-Moon distance observations for determining librations, etc.	Site, traverse	Combinations of vehicles	All phases	1	300	8,000	140	1,000	$ 2,000,000 200,000	5	60
12010202	Selenodetic surveying to establish ground control for satellite mapping	Site, traverse	Combinations of vehicles	All phases	1	290	4,000	96	1,000	$ 2,000,000 200,000	5	60
13030707	Gravity observations from lunar orbit to supplement surface observations	Orbit	None	Orbital studies	4	140	2,200	0	10	$ 10,000,000 1,000,000	5	0
13030303	Gravity measurements at lunar surface to supplement surveying observations	Site, traverse	Combination of vehicles	All phases	1	27	2,100	17	10	$ 1,000,000 100,000	5	0
13040404	Seismic measurements to supplement gravity observations	Site, traverse	Combination of vehicles	All phases	1	64	1,700	14	5	$ 200,000 20,000	5	0
				GEOLOGY								
21040101	Geologic base maps from unmanned lunar orbiters	Orbit	None	Orbital studies	0	160	5,000	0	10,000	$ 10,000,000 1,000,000	4	0
21010203	Detailed mapping of lunar surface geologic fine structure	Site, traverse	Combination of vehicles	All phases	1	38	170	5.0	100	$ 10,000,000 800,000	3	0.1 0.1
21010204	Geologic mapping, general, including on-site verification of features identified from orbital experiments	Site, traverse	Combination of vehicles	All phases	1	28	160	8.0	25	$ 8,000,000 700,000	3	0
21010309	Sample collection from all sites and traverses	Site, traverse	Combination of vehicles	All phases	1	4.1	0	5.0	0.0	$ 500,000 40,000	1	200
21040102	Photogeologic mapping from lunar orbit	Orbit	None	Orbital studies	0	75	380	0	25	$ 4,000,000 600,000	2	80
21020307	Shallow drilling for subsurface structure and sampling	Site, traverse	LSSM	Early exploration	1	44	2,000	2.9	1,200	$ 7,000,000 300,000	2	42

*Energy supplied by ALSEP RTG source
**Energy supplied by ESS RTG source

Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watts)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
GEOLOGY (Cont)												
21040205	Surface photogeology on t out	Site	Walk	Initial landing	1	33 □	960 □	3.0	100	$ 9,000,000 800,000	3	10
24030310	Age dating of lunar rocks and formations	Traverse	Combination of vehicles	All phases	1	28	40	2.0	25	$ 9,000,000 700,000	3	10
21020308	Deep-drilling for sub-surface structure and sampling	Site	Walk	Extended exploration	4	3,000	2,100,000	550	1,500	$ 50,000,000 5,000,000	3	2,000
21040411	Visual subsurface logging for fine structure	Site	Walk	Early exploration	1	1.7	45	10	100	$ 1,000,000 60,000	2	0
24030413	Paleomagnetism of the Moon	Traverse	LSSM	Early exploration	1	1.0	1.0	0.2	5	$ 400,000 80,000	1	0
22010412	Formation stratigraphic correlation over large distances by coring, etc.	Site, traverse	Rover	Extended exploration	2	110	22,000	8.0	5,000	$ 20,000,000 1,000,000	3	10
23010320	Sample collection	Traverse	Walk	All phases	1	6.0	0	0.1	0.0	$ 300,000 1,000	2	100
21010330	Subsurface sampling	Traverse	Rover	Extended exploration	1	14	0	0.2	0.0	$ 300,000 5,000	2	200
GEOCHEMISTRY												
34010401	Mass spectrometric analyses from lunar orbit	Orbit	None	Orbital studies	0	20	150,000	0	30	$ 10,000,000 500,000	3	0
32010111	Chemical analyses using neutron activation at lunar bases	Site	None	All phases	1	16	600	24	25	$ 5,000,000 500,000	3	0
32010101	Chemical analyses using neutron activation	Traverse	Combination of vehicles	All phases	1	16	25,000	500	25	$ 5,000,000 800,000	3	0
34010403	Mass spectrometry near emission sources	Emplaced points	From orbit and LSSM	Early exploration	0	20	150,000 ●	0	30	$ 5,000,000 200,000	3	0
34010402	Mass spectrometric analysis of gases on lunar surface	Traverse	Combination of vehicles	Early exploration	1	20	7,500	10	30	$ 5,000,000 200,000	3	0
31010108	Mineralogical and petrographic studies by use of microscope	Site	None	Early exploration	1	7.3	5,900	1,000	500	$ 600,000 60,000	3	0
33010102	Gamma-ray spectrometry from lunar orbit	Orbit	None	Orbital studies	0	32	2,000	0	1	$ 10,000,000 1,000,000	3	0
33010101	Gamma ray spectrometry on traverse	Traverse	Combination of vehicles‡	Early exploration	1	32	2,000	200	1	$ 5,000,000 200,000	2	0
35010110	Chemical analysis of solids using mass spectrometer	Site	None	Early exploration	1	23	600	400	30	$ 5,000,000 400,000	3	0
32010301	Distillation of solids and differential thermal analysis	Site	None	Early exploration	1	7.0	150	19	100	$ 300,000 20,000	2	5.0
32010102	Chemical analysis using IR spectrometer	Site	None	Early exploration	1	16	3,000	400	0.3	$ 6,000,000 600,000	5	0

□ Energy supplied by independent power source (Astronaut Survey Staff) Mass includes 20 KG for TV monitor located in the LEM.

● Energy supplied by independent power source (emplaced package)

‡ Experiment primarily recommended for early exploration phase may be desirable for later phases. Combination of vehicles identifies requirement for using the most advanced vehicles available in each exploration phase.

Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watts)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
				GEOCHEMISTRY (Cont)								
32010112	Chemical analysis using X-ray fluorescence at lunar base	Site	None	Early exploration	1	7.0	100	22	0.5	\$ 5,000,000 500,000	2	0
32010104	Chemical analysis using X-ray fluorescence	Traverse	Rover	Extended exploration	1	7.0	100	400	0.5	\$ 5,000,000 500,000	2	0
32010117	IR reflectance and emissivity from orbit	Orbit	None	Orbital studies	0	15	150,000	0	1,000	\$ 10,000,000 1,000,000	3	0
32010116	UV and visible reflectance spectra from orbit	Orbit	None	Orbital studies	0	15	150,000	0	1,000	\$ 20,000,000 2,000,000	3	0
32010118	IR reflectance and emissivity in situ	Traverse	Combination of vehicles‡	Early exploration	1	15	7,500	300	30	\$ 1,000,000 100,000	2	500
32010115*	UV and visible reflectance spectra in situ	Traverse	Combination of vehicles‡	Early exploration	1	15	7,500	300	30	\$ 2,000,000 200,000	2	500
32010105	Chemical analysis at base laboratory using chemical reagents, etc.	Site	None	Extended exploration	1	21	3,000	400	100	\$ 300,000 20,000	1	0
32010103	Chemical analysis using a nuclear magnetic resonance spectrometer	Site	None	Extended exploration	1	20	4,000	400	25	\$ 5,000,000 500,000	4	0
32010114	Mineralogical study with X-ray diffractometer in situ	Traverse	Combination of vehicles	Extended exploration	1	9.0	200	200	60	\$ 1,000,000 100,000	2	0
32010107	Mineralogical study using an X-ray diffractometer	Site	None	Extended exploration	1	9.0	250	400	60	\$ 1,000,000 100,000	4	0
32010113	Density measurements by gamma scattering in situ	Traverse	Combination of vehicles	Extended exploration	1	2.0	250	50	25	\$ 5,000,000 500,000	1	0
32010106	Density measurements by flotation	Site	None	Early exploration	1	0.5	0	20	0.0	\$ 100,000 1,000	0	0
				GEOPHYSICS								
40010101	Seismic velocity, surface	Site	Walk	Initial landings	1	13	1.7	0.2	20	\$ 800,000 100,000	1	0
44070882	Temperature gradient in borehole	Site	Walk	Initial landings	1	4.4	190	0.5	9	\$ 200,000 6,000	2	0
44070842	Temperature, shallow probe	Site	Walk	Initial landings	1	0.55	0	0.1	3	\$ 400,000 7,000	2	0
40080353	Meteorite measurements	Site	Walk	Initial landings	1	3.3	190	0.3	5	\$ 900,000 100,000	0	0
44070847	Thermal Diffusivity, surface	Site	Walk	Initial landings	1	6.8	12	0.3	1,000	\$ 600,000 30,000	1	0
44070850	Thermal emissivity, surface	Site	Walk	Initial landings	1	0.9	5.0	0.4	5	\$ 300,000 10,000	2	0
45030913	Gravity absolute (ESS)	Emplaced site	LSSM	Early exploration	1	15.0	18,000**	1.2	15	\$ 2,000,000 200,000	2	0
46040616	Magnetic field, determine existence of permanent lunar magnetic field	Site	Walk	Initial landings	1	6.0	250	0.3	5	\$ 800,000 100,000	1	0
46040617	Magnetic field, total	Site	Walk	Initial landings	1	7.5	160	0.5	12	\$ 800,000 100,000	1	0

‡Experiment primarily recommended for early exploration phase may be desirable for later phases. Combination of vehicles identifies requirement for using the most advanced vehicles available in each exploration phase.

**Energy supplied by ESS RTG source

Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watts)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
GEOPHYSICS (Cont)												
41020207	Seismic recording, passive	Site	Walk	Initial landing	1	11	190	1.0	11	$ 1,000,000 50,000	2	0
44070845	Temperature profile in deep borehole	Site	Walk	Early exploration	1	0.55	0	0.5	3	$ 200,000 6,000	1	0
40120778	Surface and subsurface gamma-ray spectroscopy	Site	Walk	Early exploration	1	6.0	4.5	0.5	1	$ 1,000,000 100,000	1	0
41020208	Seismic recording, passive, (long period, short period)	Site	LSSM	Early exploration	2	14	36	6.0	3	$ 1,000,000 90,000	2	0
40060565	Determination of surface and subsurface structure and formations by use of high resolution radar	Orbit	None	Orbital studies	0	100	2,400	0	10,000	$ 5,000,000 1,000,000	5	0
40120779	Surface and subsurface gamma-ray spectroscopy	Traverse	Rover	Extended exploration	1	6.0	7.0	1.0	1	$ 1,000,000 100,000	1	0
40010102	Seismic velocity, subsurface logging	Site	Combination of vehicles ‡	Early exploration	1	11	4.6	0.3	20	$ 800,000 100,000	1	0
44070848	Thermal diffusivity, borehole	Site	Walk	Initial landings	1	2.6	720	1.0	10	$ 400,000 20,000	2	0
40010103	Seismic profiling, shallow reflection	Geological area	Walk	Early exploration	1	11	4.6	0.3	20	$ 800,000 100,000	1	0
46040619	Magnetic field components	Emplaced points	Walk	Early exploration	1	6.0	18,000**	1.0	5	$ 400,000 80,000	1	0
44070843	Temperature, borehole logging	Geological area	LSSM	Early exploration	1	0.55	0	0.2	3	$ 200,000 6,000	1	0
40060630	Electrical survey, surface	Geological area	LSSM	Early exploration	1	4.3	33	1.0	500	$ 1,000,000 40,000	2	0
40060532	Resistivity of lunar surface materials in situ	Geological area	LSSM	Early exploration	1	4.0	0.001	0.2	5	$ 800,000 60,000	1	0
44070866	Passive microwave determination of surface temp. and formations	Orbit	None	Orbital studies	0	50	240	0	0.0	$ 1,000,000 200,000	5	0
45030968	Gravity gradient from orbit	Orbit	None	Orbital studies	0	50	0	0	0.0	$ 2,000,000 200,000	5	0
43030985	Orbital gravity gradient for moment-of-inertia calculations	Orbit	None	Orbital studies	0	0	0	0	0.0	$ 2,000,000 200,000	5	0
46040667	Magnetic field mapping from orbit	Orbit	None	Orbital studies	0	0	0	0	0.0	$ 800,000 100,000	1	0
41020211	Seismic recording, large array	Emplaced points	LSSM	Extended exploration	2	11	24	2.0	3	$ 1,000,000 50,000	2	0
41010206	Seismic profiling, deep refraction	Traverse	Rover	Extended exploration	0	11	0.05	0	3	$ 1,000,000 50,000	2	0
41060540	Electrical surveying, deep formations	Traverse	Rover	Extended exploration	0	6.0	0	0	10	$ 1,000,000 100,000	3	0

‡Experiment primarily recommended for early exploration phase may be desirable for later phases. Combination of vehicles identifies requirement for using the most advanced vehicles available in each exploration phase.

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Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watts)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
				GEOPHYSICS (Cont)								
44070844	Temperature and emissivity of borehole walls	Traverse	Rover	Extended exploration	1	0.55	0	0.3	3	$ 200,000 6,000	1	0
44070849	Thermal diffusivity, borehole	Traverse	Rover	Extended exploration	1	11	0.03	0.2	10	$ 500,000 10,000	3	0
40130775	Neutron activation experiment	Site	Walk	Early exploration	1	9.0	1,700	2.0	29	$ 2,000,000 500,000	3	0
40130776	Neutron activation experiment on traverse	Traverse	Rover	Extended exploration	1	6.0	1,700	0	29	$ 2,600,000 500,000	1	0
44070846	Heat flow, thermal blanket	Site	Walk	Initial landings	1	2.5	0	0.2	3	$ 1,000,000 100,000	3	0
46040618	Magnetic field, total, ESS	Emplaced points	Walk	Early exploration	1	6.0	**18,000** **	1.0	5	$ 800,000 100,000	1	0
41050541	Electrical surveying, subsurface	Geologic area	LSSM	Early exploration	0	4.0	0	0	10	$ 1,000,000 100,000	1	0
45030912	Gravity, absolute, and its variations	Site	Walk	Initial landings	1	15	**18,000** *	0.5	15	$ 2,000,000 200,000	2	0
40050524	Magnetic susceptibility, surface, in situ	Traverse	LSSM	Early exploration	1	2.0	2,300	1.0	15	$ 500,000 $ 50,000	2	0
41050622	Magnetism, remnant	Geologic area	LSSM	Early exploration	1	2.0	0	2.0	0	$ 40,000 800	1	2.0
41050623	Magnetism, remnant, late exploration	Emplaced points	Rover	Extended exploration	1	2.0	0	3.0	0	$ 40,000 800	1	5.0
45030914	Gravity survey on traverses	Traverse	LSSM	Early exploration	1	30	1,200	6.5	15	$ 2,200,000 200,000	2	0
45100601	Plasma potential variations versus height and time	Surface plus orbit	Walk	Early exploration	1	3.0	4.0	11	2	$ 200,000 100,000	1	0
46040620	Magnetic field, total field surveying	Traverse	LSSM	Early exploration	1	6.0	25	8.0	5	$ 800,000 100,000	1	0
40010104	Seismic profiling, shallow refraction	Geological area	LSSM	Early exploration	1	11	4.5	0.6	20	$ 800,000 100,000	1	0
40060534	Resistivity, subsurface	Geological area	LSSM	Early exploration	1	2.0	0.001	0.2	5	$ 2,000,000 300,000	2	0
42020284	Remote seismic station	Emplaced points from orbit	None	Orbital studies	0	3.0	12	0	1	$ 200,000 10,000	1	0
41010205	Seismic profiling, deep reflection	Geologic area	Rover	Extended exploration	2	12	4.2	2.1	20	$ 800,000 100,000	0	0
40050526	Magnetic susceptibility, subsurface	Site	Walk	Early exploration	1	2.0	300	1.0	15	$ 1,000,000 200,000	2	0
40060628	Self potential, subsurface	Traverse	LSSM	Early exploration	1	2.5	20	2.0	1	$ 1,000,000 20,000	1	0
46040621	Magnetic field survey for determining models of lunar structure	Traverse	Rover	Extended exploration	1	6.0	50	9.0	5	$ 800,000 100,000	1	0

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**Energy supplied by ESS RTG source

Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watts)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
GEOPHYSICS (Cont)												
45030915	Gravity survey, regional anomalies	Traverse	Rover	Extended exploration	1	30	1,500	31	15	$ 2,000,000 200,000	2	0
40050525	Magnetic susceptibility surface	Traverse	Rover	Extended exploration	1	2.0	300	2.0	15	$ 500,000 50,000	2	0
40060631	Electrical surveying, surface	Traverse	Rover	Extended exploration	2	4.3	36	0.5	500	$ 1,000,000 40,000	2	0
40060533	Resistivity of lunar-surface materials on traverses	Traverse	Rover	Extended exploration	1	5.0	0.001	0.1	10	$ 800,000 60,000	1	0
44070851	Temperature, surface profile	Traverse	Rover	Extended exploration	0	1.0	0	0	5	$ 800,000 60,000	2	0
40050527	Magnetic susceptibility, subsurface	Traverse	Rover	Extended exploration	1	2.0	300	2.0	15	$ 1,000,000 200,000	2	0
40060629	Self potential, subsurface	Traverse	Rover	Extended exploration	1	2.5	20	3.0	1	$ 1,000,000 20,000	1	0
44070886	Temperature probes emplaced from lunar orbit	Emplaced points	None	Orbital studies	0	20	120	0	10	$ 1,000,000 100,000	4	0
41040681	Electrical surveying, Earth current	Geologic area	LSSM	Early exploration	2	4.6	120	3.0	5	$ 1,000,000 30,000	2	0
40080370	Meteorite counter in orbit	Orbit	None	Orbital studies	1	3.7	56	0	0.2	$ 2,000,000 200,000	1	0
40050536	Electrical permittivity, surface	Geological area	LSSM	Early exploration	1	0.6	0	1.0	0.0	$ 100,000 200	1	0
40070883	Measure spectral reflectance of lunar-surface materials	Site	Walk	Early exploration	1	12	250	1.0	5	$ 3,000,000 300,000	2	0
40110777	Neutron flux and energy spectrum	Site	Walk	Early exploration	1	5.5	29,000**	0.2	5.4	$ 1,000,000 100,000	2	0
40130773	Natural radioactivity at different lunar locations	Site	Walk	Early exploration	1	1.8	1,300	1.0	8	$ 800,000 70,000	0	0
40130772	Alpha particle mass spectrometer on traverse	Traverse	Rover	Extended exploration	1	12	2.8	0	0.3	$ 1,000,000 90,000	1	0
40130774	Natural radioactivity on traverse	Traverse	Rover	Extended exploration	1	1.8	2,600	1.0	8	$ 800,000 70,000	0	0
41090487	Subsurface hardness	Traverse	LSSM	Early exploration	1	10	2.0	0	20	$ 1,000,000 100,000	4	0
40080352	Meteorite measurements, velocities, and momentums	Site	LSSM	Early exploration	1	3.3	190	0.4	5	$ 1,000,000 100,000	1	0
40070869	Spectrazonal photography to determine lunar-surface temperature and geologic formations	Orbit	None	Orbital studies	1	1.0	0	0	0.0	$ 2,000,000 200,000	2	5.0
40130771	Alpha particle mass spectrometer	Site	Walk	Early exploration	1	12	1.4	0.1	0.3	$ 1,000,000 90,000	1	0
40050538	Electrical permittivity, subsurface	Geological area	LSSM	Early exploration	1	4.0	0.02	0.1	5	$ 600,000 20,000	1	0

****Energy supplied by ESS RTG source**

Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watts)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
GEOPHYSICS (Cont)												
40050539	Electrical permittivity, subsurface	Traverse	Rover	Extended exploration	1	4.0	0.02	0.1	10	$ 600,000 20,000	1	0
40050537	Electrical permittivity, surface	Traverse	Rover	Extended exploration	1	4.0	0.02	0.1	5	$ 600,000 60,000	1	0
40060535	Resistivity of near-surface materials in boreholes	Traverse	Rover	Extended exploration	1	2.0	0.001	1.0	10	$ 800,000 60,000	2	0
40080354	Meteorite measurements on traverse	Traverse	Rover	Extended exploration	0	3.5	360	0	10	$ 600,000 50,000	2	0
47011101	Study of Earth atmosphere heat balance from lunar site	Site	Walk	Early exploration	1	78	320	27	15	$ 500,000 70,000	2	2.0
47021202	Study of Earth reflectivity and albedo	Site	Walk	Early exploration	1	17	44	25	2	$ 500,000 90,000	2	2.0
47031303	Study of Earth auroral and airglow emission	Site	Walk	Early exploration	1	13	44	20	2	$ 400,000 80,000	2	2.0
47041404	Ultraviolet scattering in Earth atmosphere	Site	Walk	Early exploration	1	17	44	20	1.5	$ 500,000 90,000	2	2.0
47051505	Earth atmosphere sounding by passive infrared scanning	Site	Walk	Early exploration	1	19	44	20	2	$ 500,000 100,000	2	4.0
47061606	Earth atmosphere density measurements by stellar refraction	Site	Walk	Extended exploration	2	3,100	40	120	20	$ 10,000,000 2,000,000	4	4.0
48092109	Study of nonterrestrial planetary atmosphere circulations	Site	None	Extended exploration	1	3,000	5.0	33	20	$ 10,000,000 3,000,000	4	9.0
48102210	Measurements of temperature and composition of planetary atmospheres	Site	Walk	Extended exploration	2	26,000	9,700	43		$100,000,000 20,000,000	9	10
40090356	Determine hardness of subsurface lunar material	Traverse	Rover	Extended exploration	0	2.0	0	0	5	$ 500,000 50,000	1	0
40120780	Orbital gamma-ray spectroscopy	Orbit	None	Orbital studies	1	28	400	0	2	$ 1,000,000 100,000	1	0
48112311	Determination of planetary albedos and reflectivities	Site	None	Extended exploration	1	3,000	230	180	9,909	$ 10,000,000 2,000,000	4	6.0
47071707	Study of Earth atmosphere during terrestrial eclipse of Sun	Site	Walk	Extended exploration	1	3,000	32	0	20	$ 10,000,000 2,000,000	4	4.0
47081808	Passive probe of Earth atmosphere by microwave scan	Site	Walk	Extended exploration	2	930	2,800	14	50	$ 6,000,000 600,000	9	0
47051512	Observations and analyses of Earth atmosphere circulation	Site	Walk	Extended exploration	1	3,000	65	50	20	$ 10,000,000 2,000,000	4	6.0
49013101	Earth ocean heat balance study	Site	Walk	Early exploration	1	69	3,200	250	15	$ 7,000,000 700,000	3	0
49023201	Sequential multiband ocean photography	Site	Walk	Early exploration	1	73	3,000	250	15	$ 3,000,000 200,000	1	2.0
49013102	Ocean heat balance study, layer phase	Site	Walk	Extended exploration	1	3,100	8,100	1,000	20	$ 20,000,000 3,000,000	5	0

Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watts)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
GEOPHYSICS (Cont)												
49023202	Sequential multiband ocean photography, later phase	Site	Walk	Extended exploration	1	26,000	26,000	820	50	$100,000,000 20,000,000	8	10
49033301	Sea surface height measurements by use of lunar-based sensor	Site	Walk	Extended exploration	1	4,000	38,000	940	50	$ 20,000,000 3,000,000	8	10
PARTICLES AND FIELDS												
52020401	Solar and galactic radiation environment at lunar surface	Site	Walk	Initial landings	2	4.8	14,000**	6.0	1.5	$ 1,000,000 200,000	0	1.0
52020201	Solar-charged particle environment at surface, 0.04 - 1000 Mev	Site	Walk	Early exploration	1	20	20,000	54	4	$ 1,000,000 300,000	2	4.0
52020101	Solar-charged particle environment at surface, 0.01 - 0.5 Mev	Site	Walk	Early exploration	1	4.6	1,200	100	3	$ 500,000 100,000	1	0
53010201	Solar wind particles at lunar surface	Site	Walk	Initial landings	1	2.3	13,000*	0.2	3	$ 0 200,000	0	0
55230101	Measure UV spectrum over solar disk	Site	Walk	Extended exploration	2	2,500	100	8.0	30	$ 10,000,000 2,000,000	5	0
55220201	Measure UV spectrum of solar flares	Site	Walk	Early exploration	1	130	3,000	7.0	10	$ 1,000,000 200,000	3	0
53050201	Monitor magnetic field strength and direction at lunar surface	Site	Walk	Initial landings	1	2.0	18,000**	2.5	2	$ 0 100,000	0	0
53010101	Solar wind interaction with Moon and geomagnetosphere	Geological area	LSSM	Early exploration	2	7.0	1,800	20	6.5	$ 2,000,000 400,000	1	0
53070101	Steady and slowly varying electrostatic field near lunar surface	Site	Walk	Initial landings	1	3.0	26,000**	3.5	2	$ 800,000 100,000	1	0
52030101	Galactic nuclei environment at surface, 100 Mev - 100+ Bev	Site	Walk	Early exploration	1	110	24,000	55	4	$ 2,000,000 500,000	1	10
55220101	Observe spectrum of outer solar corona	Site	Walk	Early exploration	1	110	30	12	12	$ 5,000,000 1,000,000	3	0
52020402	Solar energetic electrons associated with solar flares	Emplaced points	Rover	Extended exploration	2	18	120,000	91	10	$ 1,000,000 400,000	2	0
52030201	Galactic electron environment at Surface, 100 - 1000 Mev	Site	Walk	Early exploration	1	110	24,000	20	4	$ 1,000,000 400,000	2	10
52020202	Solar-charged particle environment at surface, 0.04 - 1000 Mev, later activity	Site	Walk	Extended exploration	1	25	39,000	160	4	$ 2,000,000 400,000	3	6.0
53010102	Solar wind interaction with Moon and geomagnetosphere including lunar limb measurements	Traverse	Rover	Extended exploration	3	33	34,000	39	4	$ 2,000,000 500,000	2	0
53050101	Interplanetary magnetic field and distant geomagnetic field	Site	Walk	Early exploration	2	5.0	32,000	21	21	$ 2,000,000 400,000	1	0
55220301	Measure size distribution versus time of solar photospheric granulations	Site	Walk	Extended exploration	2	1,700	400	54	100	$ 9,000,000 2,000,000	5	0

*Energy supplied by ALSEP RTG source
**Energy supplied by ESS RTG source

Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watts)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
PARTICLES AND FIELDS (Cont)												
55220601	Observe motion of solar chromospheric and coronal material in and above solar flares	Site	Walk	Extended exploration	2	1,600	80	17	25	$ 9,000,000 2,000,000	5	10
53050102	Interplanetary magnetic field and distant geomagnetic field, including lunar limb measurements	Traverse	Rover	Extended exploration	2	4.1	48,000	38	38	$ 2,000,000 400,000	2	1
53050202	Magnetic field in solar wind shock front near Moon	Orbit	None	Orbital studies	0	3.0	22,000	0	5	$ 0 100,000	0	0
52020203	Solar-charged particle environment at surface, 0.04- 1000 Mev, later activity	Site	Walk	Extended exploration	1	43	78,000	480	4	$ 2,000,000 400,000	3	10
52030102	Galactic nuclei environment at surface, 100 Mev - 100+ Bev, later solar activity	Site	Walk	Extended exploration	1	110	48,000	210	4	$ 2,000,000 500,000	3	10
52030202	Galactic electron environment at surface, 100 - 1000 Mev, later solar activity	Site	Walk	Extended exploration	1	110	48,000	76	4	$ 2,000,000 500,000	1	10
55230102	Measure UV and visible spectrum from point to point over solar disk; determine chemical composition	Site	Walk	Extended exploration	2	2,500	200	11	30	$ 10,000,000 2,000,000	5	0
55230201	Measure UV spectrum of solar flares, advanced	Site	Walk	Extended exploration	2	2,500	500	21	30	$ 10,000,000 2,000,000	5	0
55220302	Measure velocity of photospheric material in granulations	Site	Walk	Extended exploration	2	2,500	400	31	25	$ 9,000,000 2,000,000	5	0
53010103	Solar wind interaction with Moon and geomagnetosphere, several stations and solar eclipse event	Emplaced points	Rover	Extended exploration	4	33	64,000	61	4	$ 2,000,000 500,000	2	0
53050103	Interplanetary magnetic field and distant geomagnetic field, several stations	Emplaced points	Rover	Extended exploration	2	4.1	96,000	65	7	$ 0 400,000	2	0
54080101	Galactic particle scattering and reactions	Site	Walk	Early exploration	2	6.8	100	59	30	$ 5,000,000 500,000	3	0
53070102	Vertical component of electrostatic field at and above lunar surface	Site and lunar orbit	Walk	Early exploration	2	6.6	360	9.7	1	$ 200,000 30,000	1	0
53010202	Solar wind particles in shock front near Moon	Orbit	None	Orbital studies	0	2.3	13,000	0	3	$ 0 200,000	0	0
53010104	Magnetohydrodynamics of solar wind flow past Earth and Moon	Lunar surface and in lunar polar orbit	Rover	Extended exploration	4	34	130,000	140	4	$ 2,000,000 500,000	2	0
53050203	Magnetic field time variation at lunar surface	Site	Walk	Initial landings	1	3.0	22,000*	0.3	5	$ 0 100,000	0	0
53050104	Interplanetary magnetic field and distant geomagnetic field with added measurements from lunar orbiter	Surface and orbit	Rover	Extended exploration	2	7.6	210,000	110	9	$ 2,000,000 800,000	2	0

*Energy supplied by ALSEP RTG source

Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watts)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
PARTICLES AND FIELDS (Cont)												
52020301	Anistropy versus charge and energy of solar and galactic particles	Orbit	None	Orbital studies	1	11	4,300	2.3	6	$ 1,000,000 200,000	1	3.0
52020403	Solar energetic electrons associated with solar flares, lunar limb stations	Emplaced points	Rover	Extended exploration	2	18	120,000	91	10	$ 0 500,000	2	0
55220401	Observe size and magnetic field of sunspots versus time	Site	Walk	Extended exploration	2	1,700	400	16	25	$ 9,000,000 2,000,000	5	0
53040101	Electrons escaping Earth auroral zones during geomagnetic storms	Site	Walk	Extended exploration	1	4.5	5,600	220	4	$ 80,000 200,000	1	0
52090101	Solar and galactic neutrino sources	Site	Rover	Extended exploration	3	460	1,600,000	420	110	$ 30,000,000 5,000,000	9	0
54080102	Galactic particle scattering and reactions, advanced	Site	LSSM	Extended exploration	2	70	20,000	970	200	$ 10,000,000 1,000,000	6	2.0
52020103	Solar-charged particle environment at surface, 0.01 - 0.5 Mev, later activity	Site	Walk	Extended exploration	1	4.6	3,600	270	3	$ 500,000 100,000	1	0
52030103	Galactic nuclei environment at surface, 100 Mev - 100+ Bev, later solar activity	Site	Walk	Extended exploration	1	130	96,000	400	4	$ 0 1,000,000	3	20
52030203	Galactic electron environment at lunar surface, 100 - 1000 Mev, later solar activity	Site	Walk	Extended exploration	1	110	96,000	100	4	$ 2,000,000 500,000	3	10
54080103	Galactic particle scattering and reactions, detailed studies	Site	Walk	Extended exploration	2	100	200,000	88	1,500	$100,000,000 20,000,000	9	4.0
55220501	Observe structure and sudden disappearances of quiescent solar prominences	Site	Walk	Extended exploration	2	1,600	1,200	130	25	$ 9,000,000 2,000,000	5	1.0
53040102	Electrons escaping Earth auroral zones during geomagnetic storms, later solar activity	Site	Walk	Extended exploration	1	4.5	11,000	420	4	$ 80,000 200,000	1	0
52020102	Solar-charged particle environment at surface, 0.01 - 0.5 Mev, later phase	Site	Walk	Extended exploration	1	4.6	1,800	150	3	$ 500,000 100,000	1	0
BIOLOGY												
62030401	Soil bank, establish lunar sample depots at various locations on the Moon	Emplaced points	Walk and LSSM	All early phases	2	0	0	0	0.0	0 0	0	0
61040102	Evidence of existing life	Traverse	LSSM	Early exploration	2	57	7,700	270	500	$ 300,000 70,000	2	3.0
61010301	Genetic effects of lunar conditions and Earth-lunar trips on plants	Site	None	Early exploration	1	260	0	170	0.0	$ 200,000 30,000	1	0
61030303	Genetic effects of lunar conditions and Earth-lunar trips on microorganisms	Site	None	Early exploration	1	0	0	20	0.0	$ 0 0	0	0
61040101	Induced prebiotic chemistry	Site	None	Early exploration	1	45	1,500	240	15	$ 300,000 50,000	1	1.0

Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watt)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
BIOLOGY (Cont)												
61010201	Behavior and rhythms of plants under the lunar day-night cycle	Site	None	Extended exploration	1	26	30	800	0.1	$ 70,000 10,000	2	2.0
61020202	Behavior and rhythms of animals under the lunar light/dark cycle	Site	None	Extended exploration	1	1.0	0	2,400	0.0	$ 10,000 1,000	1	1.0
ASTRONOMY												
71010101	Test the influence of lunar environment on optical telescope installation	Site	Walk	Early exploration	1	50.0	300	310	20	$ 200,000 50,000	2	1.0
72010102	High-resolution astronomical photos with 12-inch telescope	Site	Walk	Early exploration	1	52	320	320	20	$ 200,000 50,000	2	
72010103	Photoelectric observations with the 12-inch telescope	Site	Walk	Early exploration	1	60	30,000	250	100	$ 200,000 50,000	2	21.0
72010104	Medium and low-dispersion spectroscopy of stars, planets, galaxies, etc.	Site	Walk	Early exploration	1	52	1,800	310	20	$ 300,000 70,000		
73020622	Investigation of the X-ray radiation from Sun, stars, galaxies and X-ray sources	Site	Walk	Early exploration	1	10	10,000	980	200	$ 500,000 100,000	2	0
73020623	High resolution study of X-ray sources	Site	Walk	Early exploration	1	25	1,000	590	200	$ 500,000 100,000	2	0
73020624	Interstellar medium distribution investigation	Site	Walk	Early exploration	1	25	1,000	390	200	$ 500,000 100,000	2	0
73030725	Detection of high-energy gamma rays	Site	Walk	Early exploration	1	25	100,000	610	200	$ 500,000 100,000	2	0
72010205	Photo survey of sky, 1000 - 3000 angstroms, with 12-inch wide field telescope	Site	Walk	Early exploration	1	51	1,600	920	20	$ 200,000 60,000	2	5.0
72010308	Photographic studies of faint and bright objects at high resolution, 40-inch telescope	Site	Walk	Extended exploration	2	3,000	300	540	20	$ 9,000,000 2,000,000	4	50
72010309	Wide-band photographic photometry at very faint limits	Site	Walk	Extended exploration	2	3,000		240	20	$ 9,000,000 2,000,000	4	50
72010310	Photoelectric photometry of selected objects	Site	Walk	Extended exploration	2	3,000	30,000	480	200	$ 9,000,000 2,000,000	4	50
72010311	Medium- and low-dispersion spectroscopy of faint stars	Site	Walk	Extended exploration	2	3,000	7,500	910	20	$ 9,000,000 2,000,000	4	55
72010312	High-dispersion spectroscopy of bright stars, nebulae, etc.	Site	Walk	Extended exploration	2	3,200	15,000	940	20	$ 9,000,000 2,000,000	4	100
72010313	Spectral scans of various objects	Site	Walk	Extended exploration	2	3,000	45,000	910	200	$ 9,000,000 2,000,000	4	50
72010414	High-resolution photographic studies with diffraction-limited 100-inch telescope	Site	Walk	Extended exploration	2	22,000	20,000	1,100	50	$100,000,000 20,000,000	6	50

Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-Hours	Peak Power (watts)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
ASTRONOMY (Cont)												
72010415	High-dispersion spectroscopy of stars, planets, nebulae, comets, etc.	Site	Walk	Extended exploration	2	24,000	60,000	1,100	50	$100,000,000 20,000,000	6	100
72010416	Systematic observations of high-energy stellar phenomena	Site	Walk	Extended exploration	2	22,000	20,000	690	50	$100,000,000 20,000,000	6	50
72010417	Determination of nature and extent of stellar outer envelope	Site	Walk	Extended exploration	2	22,000	20,000	730	50	$100,000,000 20,000,000	6	50
72010418	Photo survey for planet-like companions of stars	Site	Walk	Extended exploration	2	22,000	20,000	430	50	$100,000,000 20,000,000	6	50
72010419	Photoelectric magnitude and color index measurements of stars	Site	Walk	Extended exploration	2	22,000	40,000	1,000	200	$100,000,000 20,000,000		50
72010521	Lyman-alpha survey of the sky	Site	Walk	Early exploration	1	25	10,000	610	20	$ 1,000,000 50,000	2	0
74010520	Einstein eclipse problem	Site	Walk	Early exploration	1	20	40	62	20	$ 200,000 30,000	1	20
72010206	Investigation of variable brightness extended surface phenomena	Site	Walk	Early exploration	1	50	1,600	500	20	$ 300,000 60,000	2	5.0
72010207	Photoelectric scanning data on extended objects	Site	Walk	Early exploration	1	52	32,000	280	20	$ 400,000 70,000	2	5.0
75050102	Directional radio astronomy using interferometer	Geological area	Rover	Extended exploration	2	510	30,000	23	3	$ 500,000 100,000	1	0
75040101	Nondirectional radio astronomy	Site	Walk	Early exploration	1	7.0	15,000	6.0	3	$ 600,000 90,000	2	0
78070101	Cislunar wave propagation, study of medium	Site	Walk	Early exploration	1	20	1,500	8.0	5	$ 300,000 50,000	1	0
77070101	Lunar ambient vector magnetic field measurements	Site	Walk	Early exploration	1	5.5	5,000	57	5	$ 100,000 20,000	1	0
76070102	Lunar wave propagation experiment	Geological area	LSSM	Early exploration	2	20	51,000	19	40	$ 500,000 80,000	1	0
78070102	**Cislunar wave propagation, advanced central station**	Lunar site and earth	Walk	Extended exploration	1	20	7,500	8.0	5	$ 400,000 70,000	1	0
78070103	Cislunar wave propagation, advanced outlying station A	Emplaced points	**Flying Vehicle or Rover**	Extended exploration	1	50	7,500	8.0	5	$ 400,000 70,000	1	0
78070104	**Cislunar wave propagation, advanced outlying station B**	Emplaced points	**Flying Vehicle or Rover**	Extended exploration	1	50	7,500	8.0	5	$ 400,000 70,000	1	0
79070101	Electric field measurement from lunar orbit	Orbit	None	Orbital studies	1	2.0	2.0	0	0.4	$ 100,000 20,000	1	0
79070102	Magnetic field measurement from lunar orbit	Orbit	None	Orbital studies	1	3.3	700	0	7	$ 100,000 20,000	1	0
79070103	Particle flux measurements from lunar orbit	Orbit	None	Orbital studies	1	2.3	21,000	0	2	$ 300,000 60,000	1	0
75060101	Submillimeter radio astronomy experiments	Lunar limb, emplaced points	Rover	Extended exploration	3	5,000	20,000,000	1,000	1,000	$100,000,000 20,000,000	5	200

Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watts)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
MISSION SUPPORT INVESTIGATIONS												
82010101	Topography of proposed AAP LEM landing sites	Orbit	None	Orbital studies	1	18	5.0	0	10	X∆	X∆	100
82010103	Soil bearing strength of proposed LEM landing sites	Orbit	None	Orbital studies	1	45	93	1.0	250	$4,000,000 200,000	2	0
82010102	Engineering properties of the lunar surface	Site	Walk	Initial landings	1	1.8	0	2.0	0.0	$ 100,000 20,000	3	0
81021301	Biological contamination of lunar soil	Site	Walk	Early exploration	1	15	600	2.2	80	$2,000,000 200,000	2	1.0
82032001	Clinical monitoring	Site	None	Early exploration	2	14	70	14	5	$ 0 20,000	-	1.0
81021104	Lunar geological-geochemical sample cassettes	Site	Walk	Initial landings	1	20	0	4.0	0.0	$ 500,000 50,000	2	1.0
82010201	Lunar surface dust environment	Various locations	Walk	Early exploration	1	2.0	0	2.0	0.0	$ 100,000 10,000	1	1.0
82043401	Dust removal techniques	Site	Walk	Initial landings	1	10	5.0	1.0	500	$ 500,000 100,000	1	0
82043101	Simulated personnel shielding from solar event protons	Site	None	Early exploration	1	0.3	0	0.2	0.0	$ 0 2,000	0	0.3
82043310	Electrical systems grounding	Site	LSSM	Early exploration	1	3.0	0.2	2.0	1	$ 300,000 50,000	1	0
81021201	Electrode electrical coupling properties in lunar surface	Geological area	LSSM	Early exploration	1	2.0	0.02	4.0	5	$ 400,000 50,000	3	0
81021103	Calibration of remote sensing techniques	Selected geophysics sites	LSSM	Early exploration	1	0	0	1.0	0.0	$ 0 0	0	0
82032002	Mechanical efficiency of man at reduced gravity	Site	None	Early exploration	2	18	16	4.0	4	$ 0 50,000	-	0
82032003	Work capability determinations on lunar surface	Site	None	Early exploration	2	18	2.1	2.0	10	$ 200,000 30,000	2	0
82043502	Repair techniques for major structural damage	Site	Walk	Early exploration	2	10	1,000	3.0	1,000	$ 400,000 70,000	2	0
82032005	Vision studies	Site	None	Early exploration	1	2.3	20	0.5	40	$ 100,000 20,000	1	0.1
81021102	Lunar drill bit technology	Selected drilling sites	LSSM	Early exploration	1	0.5	0	0	0.0	$ 0 0	0	0
81021101	Gas requirements for lunar core drilling	Selected drilling sites	LSSM	Early exploration	1	0.1	0.	1.0	0.0	$ 0 0	0	0
81021203	Explosive energy coupling in lunar materials	Geological area	LSSM	Early exploration	1	10	2.7	8.0	30	$1,000,000 100,000	1	0

∆'X' Indicates classified information.

Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watts)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
MISSION SUPPORT INVESTIGATIONS (Cont)												
82053901	Explosive techniques for surface modification	Geological area	LSSM	Early exploration	1	100	0	10	0.0	$ 500,000 50,000	2	0
83064106	Detection of hydrogen in lunar materials using infrared spectrometer	Site	None	Early exploration	1	16	600	40	30	$ 200,000 100,000	5	0
83064101	Detection of hydrogen in lunar materials using neutron activation	Geological area	LSSM	Early exploration	1	16	250	5.0	25	$ 0 0	3	2.0
81021205	Stereophotogrammetry	Orbit	None	Orbital studies	2	700	2,000	8	25	$2,000,000 300,000	2	180
81021701	Earth RFI and background radio noise	Orbit	None	Orbital studies	1	15	40,000	0	10	$1,000,000 100,000	2	0
81021702	Dielectric properties of the lunar sphere	Orbit	None	Orbital studies	1	30	40,000	0	10	$1,000,000 100,000	2	0
82043414	Elastomer and polymer behavior	Site	Walk	Early exploration	1	2.5	0	2.0	0.0	$ 500,000 100,000	2	1.0
82043403	Static exposure effects on materials	Site	Walk	Early exploration	1	2.0	0	0.5	0.0	$ 200,000 40,000	1	1.0
82043404	Exposure effects on radiator materials	Site	Walk	Early exploration	1	5.0	100	1.5	100	$ 200,000 40,000	1	0
82010104	Corrosive action of lunar surface material	Site	Walk	Early exploration	1	1.0	0	1.0	0.0	$ 0 0	0	1.0
82010208	Effects of leakage from vehicles, shelters and space suits	Site	Walk	Early exploration	1	4.6	0.003	0.8	0.003	$ 500,000 100,000	1	0
82010205	Lunar atmosphere contamination effects of rocket exhaust	Site	Walk	Early exploration	1	4.6	0.003	0.8	0.003	$ 500,000 100,000	1	0
82043406	Early materials dynamic tests - machine elements	Site	Walk	Early exploration	1	20	5,000	2.0	500	$1,000,000 300,000	2	1.0
82043407	Early materials dynamic tests - thin film bearings	Site	Walk	Early exploration	1	10	2,000	2.0	200	$ 500,000 100,000	2	1.0
82043408	Early materials dynamic test - electrical components	Site	Walk	Early exploration	1	5.0	1,000	1.0	100	$ 500,000 100,000	2	1.0
82043415	Static and dynamic seals	Site	Walk	Early exploration	1	5.0	0	1.5	0.0	$ 300,000 80,000	2	2.5
82053701	Visual techniques in land navigation - astronaut vision	Geological area	LSSM	Early exploration	2	4.0	0	4.3	0.0	$ 200,000 40,000	1	0
82053702	Visual techniques in land navigation - land recognition	Geological area	LSSM	Early exploration	2	1.0	0	3.3	0.0	$ 200,000 50,000	3	0
82053602	Dangerous terrain warning techniques	Geological area	LSSM	Early exploration	1	20	2,000	2.0	20	$ 800,000 200,000	2	0

Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watts)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
MISSION SUPPORT INVESTIGATIONS (Cont)												
82053601	Soil value variations in lunar terrain	Geological area	LSSM	Early exploration	2	15	0	6.2	0.0	$ 600,000 100,000	2	0
83064105	Quantitative analysis of hydrogen in lunar material	Site	None	Early exploration	1	20	40	4.0	25	$ 0 0	4	2.0
83064104	Detection of hydrogen with a phosphorus pentoxide conductance cell	Site	None	Early exploration	1	10	40	4.0	10	$ 300,000 70,000	4	2.0
82010109	Lunar surface and subsurface electrical parameters	Geological area	LSSM	Early exploration	2	35	200	14	5	$ 300,000 40,000	2	0
82043501	Dynamics and surface environment effects on long antenna structures	Site	Walk	Early exploration	2	8.0	0	2.0	0.0	$ 300,000 50,000	1	0
82010202	Lunar RF noise, Part 1, low-frequencies	Geological area	LSSM	Early exploration	2	70	4,000	10	20	$ 400,000 70,000	1	0
82010203	Lunar RF noise, Part 2	Site	LSSM	Early exploration	1	6.0	2,000	6.5	10	$2,000,000 300,000	3	0
82010204	Antenna dust accumulation	Site	Walk	Early exploration	1	2.0	200	2.0	3	$ 300,000 50,000	1	0
81021703	Critical plasma frequencies of orbit-to-moon transmissions	Orbit	None	Orbital studies	1	12	300	5	25	$2,000,000 100,000	1	0
82043203	RF ground wave propagation	Geological area	LSSM	Early exploration	2	7.5	260	8.0	100	$1,000,000 200,000	3	0
81021801	Lunar optical astronomy test program	Site	Walk	Early exploration	2	120	1,000	20	20	$9,000,000 3,000,000	4	5.0
82023413	Solid state materials, effect of lunar environment	Site	Walk	Early exploration	1	4.0	1,000	0.2	20	$ 700,000 100,000	2	2.0
82023202	RF forward scatter techniques	Geological area	LSSM	Early exploration	2	10	150	5.0	3	$ 500,000 100,000	3	0
82010105	Radiation shielding effectiveness of lunar soil	Site	Walk	Early exploration	2	10	0.2	13	1	$1,000,000 300,000	2	0
82010108	Shelter shielding and construction support properties of lunar soil	Geological area	LSSM	Early exploration	2	6.5	2.0	5.0	2	$ 800,000 200,000	2	0
82043301	Lunar surface transmission line interactions	Site	Walk	Early exploration	1	2.0	0	2.0	0.0	$ 200,000 50,000	1	2.0
82043402	Damage to lunar equipment	Site	Walk	Early exploration	1	0	0	3.0	0.0	$ 0 0	2	0
82010206	Thermal radiation intensities and surface temperature gradients	Geological area	LSSM	Early exploration	1	10	100	2.0	50	$ 200,000 50,000	1	0
82043201	Lunar environment effects on antenna systems	Geological area	LSSM	Early exploration	1	7.0	100	3.0	2	$ 400,000 80,000	2	0
82043206	Retrodirective optical system techniques	Geological area	LSSM	Early exploration	2	3.0	50	1.0	5	$ 300,000 50,000	1	0

Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watts)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
MISSION SUPPORT INVESTIGATIONS (Cont)												
82010122	Lunar strata electromagnetic propagation parameters	Geological area	LSSM	Early exploration	2	3.0	250	7.5	100	$1,000,000 200,000	2	0
82045003	Temperature/density stratification of cryogenic liquids	Site	None	Early exploration	1	1.0	0.01	0	0.001	$ 200,000 50,000	1	0
82054001	Metals joining techniques in lunar surface construction and repair	Site	Walk	Extended exploration	2	20	10,000	18	10,000	$ 300,000 80,000	3	0
82043405	Materials dynamic test program	Site	LSSM	Extended exploration	1	80	20,000	20	800	$1,000,000 400,000	2	3
82043204	RF subsurface propagation	Geological area	Rover	Extended exploration	3	20	350	11	100	$ 800,000 200,000	3	0
82043205	Laser scatter propagation	Traverse	Rover	Extended exploration	3	80	100	4.0	50	$ 500,000 200,000	2	0
82032011	Bone demineralization studies	Site	None	Extended exploration	2	65	10,000	55	1,000	$ 0 50,000	0	1.0
82033004	Effects of breathing various gas mixtures	Site	None	Extended exploration	2	30	0	23	0.0	$ 300,000 50,000	2	0
82033002	Use of lunar soil for microorganisms and higher plants	Site	LSSM	Extended exploration	1	300	34,000	140	1,700	$2,000,000 300,000	3	0
81021207	Earth reference gravimeter	Site	Walk	Extended exploration	2	5.0	8,000	16	1	$2,000,000 200,000	2	5.0
82032006	Psychological studies	Site	None	Extended exploration	2	7.0	0	20	0.0	$ 100,000 1,000	1	0
82032004	Bioassays of body fluids	Site	None	Extended exploration	2	3.5	0	21	0.0	$ 0 5,000	0	0
82032010	Cardiovascular phenomena	Site	None	Extended exploration	2	7.3	900	55	20	$ 100,000 20,000	1	0.5
82045001	Heat transfer in liquids through natural convection	Site	None	Extended exploration	1	7.0	5.0	10	300	$ 200,000 40,000	2	0
82045002	Heat transfer in film and drop condensation processes	Site	None	Extended exploration	1	3.0	2.0	10	100	$ 200,000 50,000	2	0
83064201	Characteristics of lunar ores - self welding	Geological area	LSSM	Extended exploration	1	5.0	0	4.5	0.0	$ 200,000 50,000	2	0.5
83064303	Particle adhesion in mechanical processing	Geological area	LSSM	Extended exploration	1	400	10,000	24	1,500	$1,000,000 300,000	3	4.0
83064501	Lunar dry cement and concrete applications	Geological area	Rover	Extended exploration	2	110	7,000	51	1,500	$ 500,000 100,000	4	5.0
83064102	Chemical and differential thermal analysis for oxygen and CO_2 sources	Site	None	Extended exploration	1	15	320	10	100	$ 0 0	2	1.0
83064103	Differential thermal analysis of potentially castable materials	Site	None	Extended exploration	1	5.0	15	10	100	$ 0 0	2	1.0

Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experiment No.	Experiment Title	Experiment Location	Mobility Requirement	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watts)	Nonrecurring and First Item Costs	Development Time (years)	Earth Return Weight (kg)
MISSION SUPPORT INVESTIGATIONS (Cont)												
82043409	Long-term static exposure effects on materials	Site	Walk	Extended exploration	1	5.0	40	3.0	40	$ 400,000 100,000	1	2.0
82010207	Lunar impact spherics	Site	Walk	Extended exploration	1	20	1,000	2.4	1	$ 600,000 100,000	1	0
82021802	Remote occulting disk as solar coronograph	Geological area	LSSM	Extended exploration	2	20	0	6.7	0.0	$ 300,000 50,000	1	0.2
82010107	Lunar seismic environment	Site	LSSM	Extended exploration	1	10	20,000	1.0	5	$ 200,000 40,000	3	0
82033001	Evaluation of algae strains	Site	None	Extended exploration	1	320	14,000	210	1,700	$2,000,000 300,000	3	4.5
82033003	Evaluation of hydrogenomonas strains	Site	None	Extended exploration	1	320	2,000	210	120	$2,000,000 300,000	2	15
82033006	Evaluation of hydrocarbon utilizing organisms	Site	None	Extended exploration	1	320	14,000	110	1,700	$2,000,000 300,000	2	0.2
82033005	Biological monitor and eco-system prototype	Site	None	Extended exploration	1	10	12,000	10	50	$ 200,000 50,000	3	0.01
82010106	Nuclear reactor emplacement assessment	Site	LSSM	Extended exploration	2	16	0.47	10	0.49	Common usage equipment	2	0
82043302	Electrical transmission line routes	Site	LSSM	Extended exploration	2	0	1,000	6.0	100	$ 0 200,000	0	1.0
82033007	Effects of lunar conditions on plants	Site	None	Extended exploration	1	470	500	85	10	$2,000,000 400,000	2	10
82033008	Growth, development, reproduction and survival of plants	Site	None	Extended exploration	2	470	6,000	500	60	$2,000,000 400,000	2	200
82033009	Genetic effects of lunar conditions and earth-lunar trips on animals	Site	None	Extended exploration	1	470	0	100	0.0	$2,000,000 400,000	2	0
82033010	Growth development reproduction and survival of animals	Site	None	Extended exploration	2	470	0	500	0.0	$2,000,000 400,000	2	68
81021503	Lunar plasma properties near surface	-	-	Early exploration	These experiments have no lunar surface support requirements. The information from other experiments is correlated on Earth to obtain other desired information. See type-0 card.							
81021105	Sampling survey techniques	-	-	Early exploration								
83064107	Hydrogen detection and analysis techniques	-	-	Early exploration								
82053902	Digging and cutting tool assessment	-	-	Early exploration								

Table 5. Experiment Summary Information (SMS-ELE) (Cont)

Experi-ment No.	Experiment Title	Experiment Location	Mobility Require-ment	Exploration Phase	Men Req'd	Equip. Mass (kg)	Energy (watt-hr)	Total Man-hours	Peak Power (watts)	Nonrecur-ring and First Item Costs	Develop-ment Time (years)	Earth Return Weight (kg)
MISCELLANEOUS BASIC AND APPLIED RESEARCH												
90050201	Corner reflectors for laser beams	Emplaced points	LSSM	Early exploration	1	30	0	0.4	0.0	$ 200,000 50,000	1	0
90030301	Heat convection and flow of gases	Site	Walk	Early exploration	1	20	100	3.0	20	$ 500,000 100,000	2	0
90010101	Generation of high-intensity electron beams	Site	Walk	Extended exploration	1	15	10,000	20	50,000	$1,000,000 200,000	2	0
90030201	Solar furnace with controllable focal energy flux	Site	Walk	Extended exploration	1	100	1,000	15	50	$ 800,000 200,000	2	0
90010201	High-intensity arc generation in lunar environment	Site	Walk	Extended exploration	1	25	3,000	15	10,000	$1,000,000 300,000	2	0
90030101	Radiation cryostat	Site	Walk	Extended exploration	1	10	100	20	1	$ 500,000 100,000	2	0
90020101	Field emission optics	Site	Walk	Extended exploration	1	3.0	1,000	15	100	$ 800,000 200,000	2	0.5
90050101	Lorentzian plasma environmental physics	Site	Walk	Extended exploration	2	10	40	4.0	20	$ 400,000 100,000	2	0
90040101	Lifetimes of atomic species	Geological area	Rover	Extended exploration	2	100	2,000	70	200	$1,000,000 300,000	4	0

5.0 SYSTEM AND SUBSYSTEM IMPLICATIONS

5.1 ASTRONAUT CAPABILITIES

5.1.1 Background

Man's capability and limitations will be a major factor in lunar exploration. His use in the performance of scientific experiments and in mission support activities will be a prime requirement for contemplated lunar missions because of his ability to observe, think, and then act, especially with regard to unexpected events. Contingencies, due either to natural phenomena or to system and subsystem performance, will continuously arise, which will justify man's participation in the program. Man's inclusion will be a major factor in the definition of experiments, the design and sizing of equipment, and the development of operational procedures as well as in mission formulation and systems support.

Major considerations governing the development of work programs for astronauts performing scientific missions arise from interactions among task requirements, reduced traction, and suited performance decrements and their total effect on astronaut performance capabilities and characteristics. During lunar operations, the astronaut will be required to perform in environments demonstrated by previous experimentation to produce significant decrements in the productivity, capability, and efficiency of operators. An increasing amount of experimental evidence is available to conclusively demonstrate that human performance capabilities and characteristics are adversely altered in significant fashion when operator performance entailing either manual outputs or body translations is required in reduced traction and/or pressurized, suited environments.

A major portion of astronaut energy expenditures in lunar surface operations may be associated with two types of activities: those attendant to surface travel, and those attendant to the execution of work tasks.

5.1.2 Astronaut Surface Mobility

A considerable amount of effort has been expended in investigating the output characteristics of man while walking on a variety of surfaces under normal terrestrial conditions. The results of two studies are presently available which have investigated walking characteristics in reduced traction environments. The results reported are almost diametrically opposed to each other. One investigator (Reference 3) reports significant increases in the energy costs of walking in reduced traction environments, and the other investigator (Reference 4) reports significant decreases in the energy costs of walking in reduced traction environments. At this time, experimental results indicating increased walking efficiency and decreased directional stability, coupled with gait alterations, in reduced traction environment may be accepted with reservations until future clarification of these apparent anomalies.

The earliest investigations of operator capability in pressure suits have been confined, for the most part, to examinations of operator output characteristics while walking. The experimental evidence available indicates that pressure suits may be expected to increase man's energy expenditure while walking by a factor of at least three. It also appears that walking task times should be multiplied by a factor of two when based on comparable shirtsleeve time. This increase has implications to system designers and mission planners that cannot be overlooked, as will be discussed in a later section.

It is apparent that, with respect to activities attendant to the transport of the operator and ancillary equipment to and from various work areas, many questions concerning astronaut fatigue and subsequent work capabilities and, concomitantly, walk-back capability, remain unanswered.

5.1.3 Work Capability

In considering work capability, the effects of reduced gravity and pressure suits on the work output characteristics of the human operator performing manual work, must again be considered. Experimental data descriptive of man's capabilities and characteristics during the performance of manual tasks in such environments demonstrate that the progressive removal of traction produces progressively larger decrements in operator force and work producing capabilities that result in capability degradations sufficiently large to require re-evaluation of present concepts of system sizing and mission task requirement planning. Decrements have been manifested, singly or in combination, as reductions in force and work producing capabilities increase the total task accomplishment times.

Present test data indicate that if lunar-suited workers are required to exert and produce respectively significant amounts of manual force and work, then an appropriate bracing-restraint system must be employed to effect either a fixed man-loose object or a fixed man-fixed object configuration. Maximum efficiency is obtained in bracing-constraint systems when they are designed in such a way that the applied and the reactive forces lie in the same plane and along the same line of action.

Experimental evidence exists (References 9 through 16) indicating that a pressurized suit impairs the operator capability to an extent that overrides all other considerations. These impairments have been manifested as reductions in operator mobility and manual dexterity, work and force producing capabilities, operator efficiency, etc. Increases of 400 percent in task accomplishment times have been reported in References 10, 11, 14, and 15 to be solely attributable to wearing pressurized suits.

These factors are of considerable significance; however, the most important factor in work cycle schedule development is the integration of these decrements in performance characteristics with the human characteristic that maintains energy expenditure rates during self-paced work at a level sufficiently low to prevent oxygen debt formation. This self-regulatory phenomenon usually results in the selection of a maximum energy expenditure rate of approximately 1300 Btu per hour and a typical expenditure rate of approximately 800 to 900 Btu per hour (Reference 5). It is normally anticipated that operator efficiency ranges from 12 to 16 percent during the performance of manual tasks (Reference 5). If the operator performs in a self-paced mode with an anticipated expenditure of approximately 800 to 900 Btu per hour, any degradation imposed upon his output capabilities by suits or environment will cause him to lower his output rate to maintain himself in an oxygen debt free state. Thus, more time will be required per work cycle to be executed. As a consequence, design engineers can choose one of two alternatives: reduce operator workload or allocate more man-hours per unit task required. These approaches yield the same net resultant increase in energy expenditure per unit task accomplished. Present system design concepts require provision of a supply of breathing gases sufficient to maintain the operator for 4 hours at an average energy expenditure rate of 1600 Btu per hour and a peak value of 2000 Btu per hour (Reference 6). The mean value appears to be in excess of anticipated operator requirements, while the peak value of 2000 Btu is far below the requirements that can be engendered by man in an emergency.

5.1.4 Conclusions

A study should be made to assess the impact of the preceding considerations on time allocations for representative aspects of the work schedule. As part of the same study, an experimental program should be initiated to determine the following:

1. The ratio of lunar to terrestrial task accomplishment times

2. The ratio of lunar to terrestrial operator work efficiencies

3. The ratio of lunar to terrestrial operator capabilities with reference to force and work producing capability

4. The physiological cost of work in these environments as modified by the nature of the astronaut suit, availability and nature of bracing/restraint devices, breathing gas mixtures, special tools, terrain, and other environmental considerations

In the absence of quantitative data, predictions can only be made which are based on information presently available (Volume 3, Detailed Technical Report). Based on such preliminary information, it is recommended that a time ratio of a least 4:1 be used in converting time requirements for work task accomplishment from Earth to lunar environments. Correspondingly, an average energy output by the operator of approximately 1200 to 1300 Btu per hour should be allowed, and more rest periods should be programmed.

It is anticipated that force-production capabilities can be no more than 50 to 60 percent of Earth values under ideal conditions. Bracing-restraint systems should be provided during the production of work that is more than momentary in duration.

In Section 5.1.2, an energy expenditure increase of three was indicated for walking in a pressure suit. When walking on the lunar surface, the expenditure will be increased due to nonoptimal surface conditions and reduced gravity. References 4, 10, and 11 indicate that a time ratio of approximately 2:1 appears to be reasonable for walking short distances in the lunar versus Earth environments. However, for an energy expenditure rate of about 1600 Btu per hour, this time ratio cannot be sustained, and extensive use of wheeled locomotion will be required to minimize walking expenditures.

Finally, improvements in the pressurized suit and use of special aids should be made to enhance astronaut effectiveness in supporting lunar scientific missions.

5.2 MOBILITY IMPLICATIONS

Mobility is a vital capability for supporting lunar exploration. The basic areas of application for mobile support systems are:

1. Surface locomotion or rocket-propelled surface-to-surface transportation of men and equipment

2. A capability for mission abort or rescue

3. Power, environmental control and data systems, a platform for mounting instruments and functional equipment such as drill subsystems, and other investigation support capabilities

4. Augmentation of life-support capabilities for local exploration

5. Environmentally controlled facilities for laboratory operations, crew support, and navigation and control for extended exploration

6. A capability for off-loading and deploying equipment

7. A capability for surface modification

8. Support of mining and materials-handling operations.

Table 6 presents the distribution of mobility requirements specified for the experiments compiled in this study, within each of the ten discipline areas. The "None" heading relates to experiments that do not require direct

Table 6. Specified Mobility Requirements Distribution

	Specified Mobility Requirements					
	None					
Discipline Area	Surface, Indoors	Orbit	Walk	LSSM	Rover	Combination of Vehicles
Lunar Atmospheres	0	0	2	2	2	0
Geodesy	0	2	0	0	0	5
Geology	0	2	4	2	2	4
Geochemistry	10	4	0	1	1	7
Geophysics	0	10	42	18	23	1
Particles and Fields	0	3	33	2	9	0
Biology	5	0	1	1	0	0
Astronomy	0	3	29	1	4	0
Mission Support	26	6	27	30	3	0
Investigations[1]				1		
Miscellaneous Basic and Applied Research	0	0	7	1	1	0
Totals	41	30	145	58	45	17

[1]Four corollary experiments are not included. These experiments require no support on lunar surface. See Table 5, "Experiment Summary Information (SMS-ELE), p. 60.

surface mobility support, including those which are performed in lunar orbit and those which are performed exclusively in the shirtsleeve environment of a lunar shelter. The "Walk" heading refers to requirements for on-foot movement by a suited astronaut ranging from airlock egress/ingress to kilometer-level movements across local lunar terrain. The "LSSM" heading represents requirements for short-range, open-cabin mobility support within a geological area of approximately 8-km radius. It also represents duration requirements which can be satisfied by life support extension with additional backpack(s). The "Rover" designation represents requirements for mobility support by a closed-cabin, long-range surface vehicle encompassing a spectrum of potential needs ranging from 100 to 1600 km, 14 to 90 days, and 2 to 3 men. Mobility requirements for the deployment of a long-wave radio telescope and a 100-inch horizontal telescope system are special construction requirements and are discussed in Section 5.3. The requirements reflected in Table 6 include only those requirements in direct support of each experiment.

It is important to note that the ground rules for specifying mobility requirements were to indicate the lowest level of mobility required for the performance of each experiment. As will be discussed in the following text and under Astronaut/Vehicle Implications, the designated mode is not necessarily the optimum approach. In general, the LSSM mobility requirements heading indicates an early exploration phase activity. However, possible applications for the LSSM in extended exploration also are indicated in the experiment compilation presented in Volume 5 (Appendix B) and in the Experiment Descriptions Section in Volume 3. Requirements for the larger surface vehicle of the Rover class imply investigations to be performed in later phases of extended lunar exploration. The title "Combination of Vehicles" as used in the Experiment Data System identifies mobility requirements for local (LSSM-type) support in the early exploration phase and then extension of the scope of the same experiments in the extended exploration phases utilizing a Rover when available. This heading is also employed in Table 6 . The only case where vehicles are defined as being utilized simultaneously in "combination," in the sense of "working together," is in the erection of the long-wave radio telescope.

Table 6 classified the mobility requirements specified in the Experiment Summary Information Table 5 (Section 4.4). These, in turn, are based on the experiment Type-1 card printouts in Volume 4 with the exception of two experiments which were encoded as requiring a Flying Vehicle, but summarized as "Flying Vehicle or Rover" to indicate alternatives, and entered in Tables 6 and 7 as a "Rover" requirement.

Table 7 presents mobility requirements for experiment support in terms of two alternate criteria, minimum mobility and the mobility capability which provides for the most effective performance of each experiment. The "Minimum Mobility" portion was obtained by transferring the specified "Combination of Vehicles" requirements to "LSSM" requirements. The requirements for "Most Effective Mobility" have been derived by reviewing each experiment individually and identifying the mobility mode for most effective performance, either from the standpoint of efficiency of performance or scope of data to be derived. Under the latter criterion, the previous "Combination of Vehicles" requirements logically are expressed as "Rover" requirements. A detailed listing of experiments with "Minimum" and "Most Effective" mobility requirements appears in Table 19 of Volume 3.

Table 7 . Mobility Requirements Comparison

Discipline Area	None Req'd	Minimum Mobility			Most Effective Mobility		
		Walk	LSSM	Rover	Walk	LSSM	Rover
Lunar Atmospheres	0	2	2	2	2	2	2
Geodesy	2	0	5	0	0	0	5
Geology	2	4	6	2	1	1	10
Geochemistry	14	0	8	1	0	1	8
Geophysics	10	42	19	23	37	21	26
Particles and Fields	3	33	2	9	30	2	12
Biology	5	1	1	0	0	1	1
Astronomy	3	29	1	4	26	4	4
Mission Support Investigations[1]	32	27	30	3	18	22	20
Miscellaneous Basic and Applied Research	0	7	1	1	5	3	1
Totals	71	145	75	45	119	57	89

[1]Four corollary experiments are not included. These experiments require no support on lunar surface. See Table 5,'Experiment Summary Information (SMS-ELE)," p. 60.

The collation and definition of investigations and experiments in this study have been directed primarily toward defining the objectives, parameters, equipment support requirements, and experiment sequencing; the study does not consider geographical distribution or mission scheduling in a quantitative way. Consequently, distance requirements beyond those desired for a "Rover" class of vehicles are not derivable directly from this study. Integration of experiments into alternate traverse missions is a recommended future activity that can contribute to trade-off analyses. An additional consideration in such a study should be the number of repetitions of experiments required at different locations representing different geological or geophysical "units." Such analysis would yield a more comprehensive picture of experiment operations requiring advanced mobility support.

5.2.1 Local Surface Mobility Support

The astronaut lunar capabilities discussed in the previous section indicated excessive metabolic costs, and reduced walk and work capability leading to a serious man-hour growth. Based on these data as well as on experiment support requirements defined in the experiment compilation, the review of local mobility support requirements performed in this study indicates that in addition to the normal function of a personnel and logistics carrier, the vehicle should be considered as a prime component in experiment performance. Man-machine integration should emphasize total mission effectiveness. The study indicates that local surface mobility support is required to:

1. Extend the capability of the astronaut to safely negotiate varied terrain
2. Substantially reduce the time required for movement on the lunar surface, whether the distance travelled is a few meters or kilometers
3. Reduce astronaut fatigue by facilitating vehicle-seated low-energy operations
4. Extend the duration limits for astronaut surface operations by reducing metabolic costs and supplying backup life support
5. Increase the allowable radius of local exploration (also strongly dependent on suit)
6. Transport experiment and support equipment
7. Provide for mounting of equipment such as drill, sample cassettes, penetrometer, ground-truth sensors, Jacobs staff, explosives, and ESS components.
8. Provide subsystems support, such as power and data systems
9. Support experiment performance by providing special aids and restraints. Since the vehicle would be equipped with restraining harnesses, potential experiment aids include a tilt-forward seat to yield a restrained work position

Table seven indicates 145 requirements for walking mode support and 75 requirements for LSSM-type mobility support based on a minimum mobility criterion. For most effective performance of experiments, many requirements are upgraded, resulting in a reduction of walking mode support to 119 and of LSSM-type support to 57 (in favor of a Rover, if available).

5.2.2 Extended Surface Mobility

Long-range surface mobility will be required during extended lunar exploration phases to satisfy the following lunar scientific objectives defined by the National Academy of Sciences at Woods Hole, Mass. during the summer of 1965.

"Investigations on the lunar surface are needed on at least three different scales. The smallest features, ranging in size from near microscopic to hundreds of meters, the fine structure of the lunar surface, can be studied by men on foot during early Apollo landings. Very detailed investigations of features at this scale and the processes by which they are produced may require a small lunar base to sustain men over much longer periods of time than is available during the early Apollo landings. To study features ranging in size from one to many kilometers requires a vehicle to carry men over these distances from the landed spacecraft. This is the scale on which most of the contact relations of regional geologic units and mesoscale structures, such as relatively large craters, faults, folds, and possible igneous intrusions and volcanoes must be examined. Finally, surface traverses of ten to hundreds of kilometers in length are required to examine features of crustal and subplanetary dimensions, such as the basin and surrounding mountain ring of Mare Imbrium and other circular maria. These traverses are needed to obtain deep seismic reflection and refraction profiles correlated with surface gravity measurements and geology. Such traverses provide extensive opportunities to sample and study areal variations in the regional geologic units."

Forty-five experiments in the present study specify a long-range traverse capability. However, for most effective performance, the number of experiments needing a Rover support capability is 89.

5.3 LUNAR SURFACE SCIENTIFIC OBSERVATORIES

Many of the fundamental experiments for extended lunar exploration require facilities to be emplaced on the lunar surface. Major facilities are visualized to be used in support of astronomy experiments which are intended for long-duration occupancy on the order of many months to several years. In order to define typical major support requirements, two scientific observatory-type facilities were studied. One is a radio telescope system for lunar long-wave radio astronomy; the second is an optical astronomy observatory facility employing a 100-inch aperture telescope. Emphasis was placed on packaging concepts compatible with launch vehicle payload considerations and on deployment requirements after lunar landing.

Generally, packaging requirements are flexible and there appears to be no special problem for either type of installation. Optical astronomy will require special payload design. Deployment requirements can be satisfied by mission support equipment presently envisioned for the middle phases of extended lunar exploration with the addition of special construction modules attached to the longer-range roving vehicles.

5.3.1 Lunar Long-Wave Radio Telescope

The lunar environment offers great potential for attainment of outstanding performance of radio telescopes. The low surface temperature during the lunar night, the potential utilization of the lunar back side as a shielded environment, and anticipated advancements from future research programs combine to offer the possibility of major gains in the study of the universe at radio wavelengths. Operation at long wavelengths beyond those receivable on Earth is desired to complement Earth-based radio astronomy. Applications would include resolving and locating galactic and extragalactic sources—spiral arms, core and halo structures, supernova remnants, gaseous nebulae, and very distant radio stars.

A preliminary design concept was developed for a long-wave radio telescope for possible later application to a lunar radio astronomy observatory. Weight, packaging, and deployment were briefly investigated for utilization in the concurrent MIMOSA study.

Installation and initial operation of the long-wave radio telescope as a major system in a lunar long-term radio astronomy observatory appears feasible in the second half of the 1970's.

The concept is a broadband crossed array or Mills-Cross illustrated in Figure 4 . The nominal design frequency is 1 MHz, corresponding to a wavelength of 300 meters. The frequency range of 0.3 to 1 MHz is considered, with possible extension to 10 MHz. A resolution in the neighborhood of at least one square centimeter degree at 1 MHz is desired with sufficient separation between the interference fringes to avoid ambiguities in pointing, identification, and measurements. To provide a 1-degree resolution capability at 1 MHz, an antenna baseline of 18 kilometers is required.

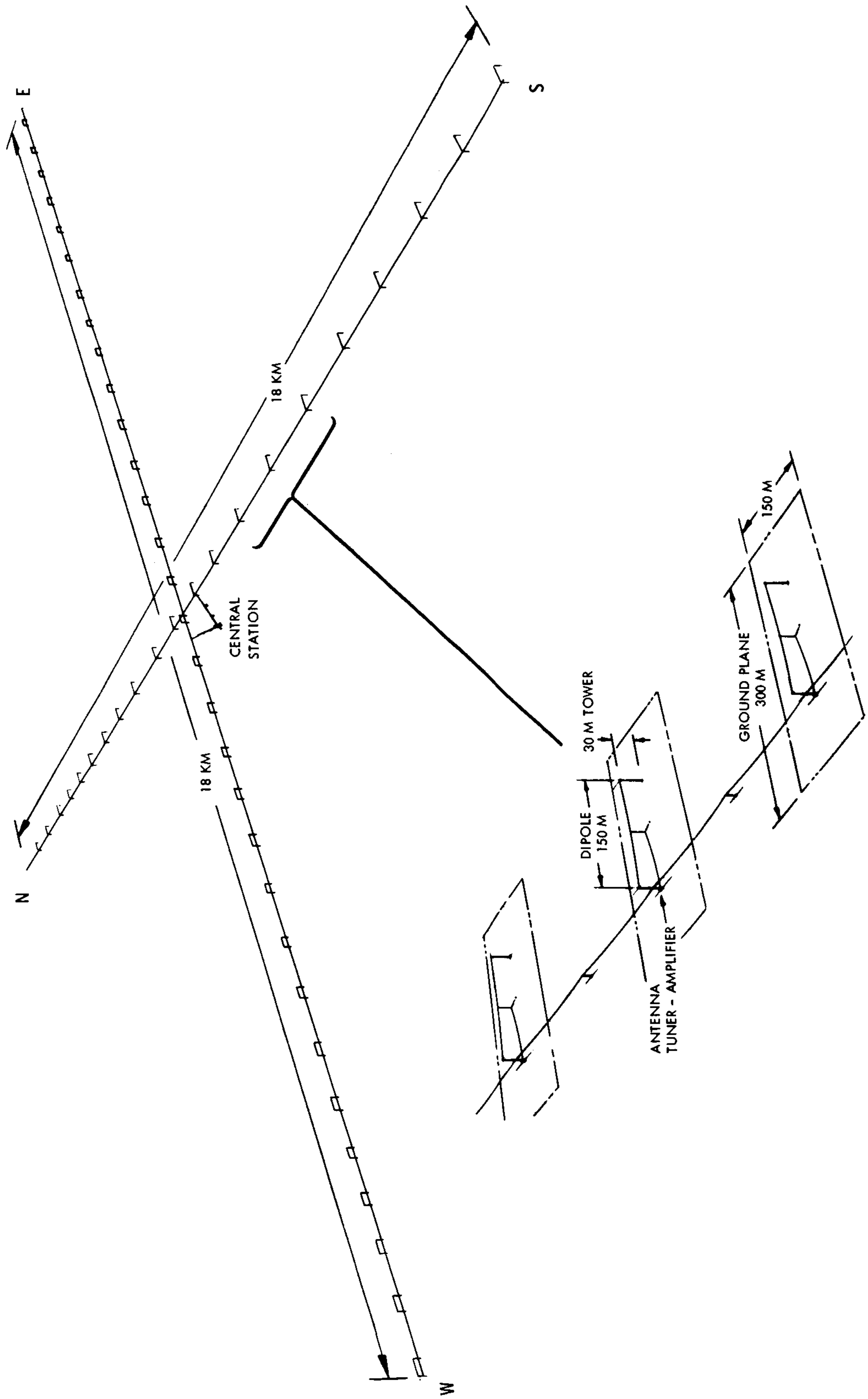

Figure 4 . Long-Wave Radio Telescope — Mills-Cross Concept

The N-S and E-W arrays each contain 48 half-wave dipoles per array cut for the center frequency of 1 MHz. Each dipole is 150 meters long.

The twin-lead feeding each dipole is utilized as a tuned line or a folded section of the antenna, depending on whether the antenna is operated above or below the center frequency of 1 MHz. The lower end of the twin-feed line is connected to an antenna tuner and amplifier unit housed near the base of the antenna tower. The N-S and E-W transmission lines are supported about 10 meters above the ground. The antenna height tentatively shown at 30 meters, which is one-tenth of a wavelength at 1 MHz, is rather close to the lunar surface. For a ground having a conductivity in the neighborhood of 3×10^{-4} mhos per meter, from reflectivity measurements of the Moon, the proximity loss becomes substantial at and below 1 MHz. To reduce this loss, a ground screen or counterpoise of wires is required.

The 30-meter antenna towers are of telescoped design. Deployment would be performed using a large roving vehicle equipped with light construction support modules. Additional mobility consisting of a LSSM operating as a surveying and support vehicle appears desirable.

The initial weight estimate for the complete interferometer system is 27,500 pounds, or 12,500 kilograms.

A preliminary packaging concept for the long-wavelength radio observatory was developed which shows that the radio telescope can be packaged in a cylindrical section 78 inches high and 240 inches in diameter. By increasing the cargo compartment to 144 inches, additional construction equipment and a short-range surface mobility vehicle can be included.

The initial configuration of the proposed lunar-based radio astronomy telescope should be "open-ended," allowing for future extensions of the antenna arrays for improving angular resolution and for measuring signal polarization phenomena. Step-by-step improvements of the initial signal processing and recording methods must be facilitated by the use of modular circuit components with well-matched input and output impedance characteristics and synchronized by a central clock system of sufficient accuracy.

The expected major phases in this growth would be operation of a single-beam system, two-beam operation, large field recording technique, and linear extension of the Mills-Cross array.

Resolution of a number of critical system parameters is required, ranging from the choice of step-frequency or sweep-frequency receiving and detection techniques to the height of dipoles. It is also required that techniques be developed and proven leading to provision of self-extendable or erectable support towers for ease of field deployment. It is suggested that techniques developed on Earth and refined in orbit be tested on the lunar surface in an earlier mission. The beam width, unwanted side lobes, and accuracy of pointing will all depend on the degree of correct alignment, as well as on the constancy of the adjustment with the lunar environment and the stability of the component parts. Therefore, it is required that techniques be developed for calibration, adjustment, and phase alignment of the antenna array and its component parts. This will be aided greatly by the experimental erection and testing of a similar array on Earth.

5.3.2 100-Inch Telescope Concept

As a part of the major scientific equipment definition activities, a concept of a 100-inch horizontal telescope developed under a previous contract (Reference 7) was reviewed briefly. The review was directed primarily toward providing performance, packaging and deployment, and support data.

The optical concept of the 100-inch horizontal telescope was suggested previously by Dr. G.H. Herbig of the Lick Observatory (Reference 7). The primary objective is to take advantage of unique features of lunar-basing to maximize telescope performance so that major scientific returns can be realized. To achieve this objective, the optics must be diffraction-limited for effective operation in the 1000 to 1500 Å region. An aperture of not less than 100 inches is desired, for which the theoretical resolution is about 0.01 arc second.

Other conditions considered are:

1. To achieve this performance, the telescope must be designed to feed fixed receivers that can be operated under shirtsleeve conditions. Adequate radiation shielding for personnel must be provided at the same time.

2. The large optics and other critical components must be protected from major thermal perturbations and from moving solid material near the lunar surface.

3. To the extent feasible, full advantage must be taken of the peculiarities of the lunar environment in departing from conventional telescope design.

The original concept, modified for packaging considerations and shown in Figure 5 , includes a 200-inch aperture optical flat siderostat in a protecting dome, a 100-inch aperture primary, a 12.5-inch secondary mirror, a long-focus reflecting grating, a rotating photographic film or plateholder, and a photoelectric photometer. The 100-inch and 12.5-inch mirrors are

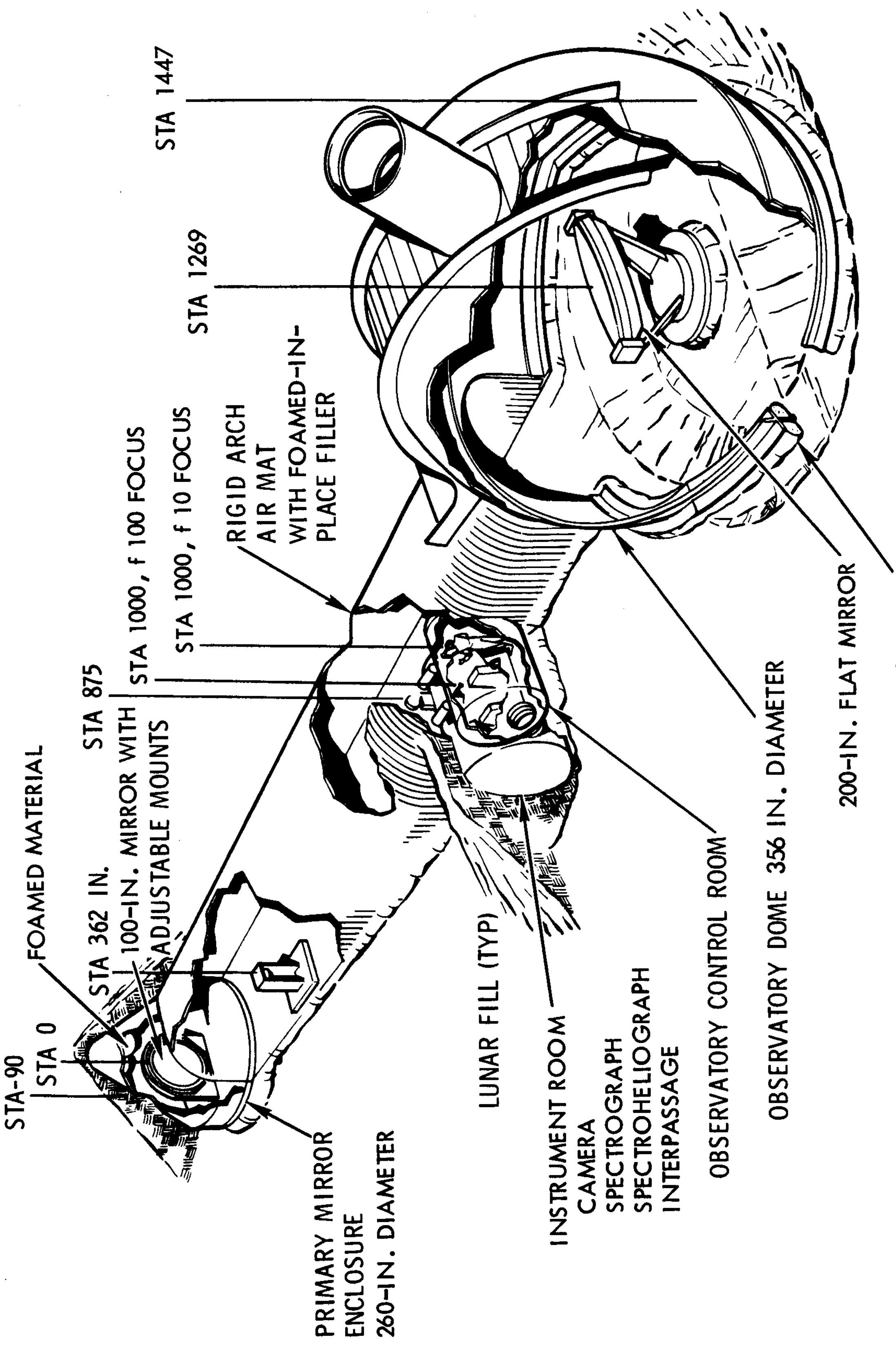

Figure 5. 100-Inch Telescope Concept (Modified From Reference 7)

off-axis portions of 240-inch and 30-inch mirrors, respectively, mounted so that there is no obstruction of the primary mirror by the secondary mirror.

In support of packaging and deployment, an analysis was made which resulted in a reduction in size of the large movable dome and a shortening of the tunnel with a corresponding decrease in payload weight. The dome was reduced to 356 inches O. D. for packaging in a 396-inch O. D. payload concept. Also, the siderostat and dome were moved toward the primary, displacing some 28 feet of light tunnel. Overall length is 37 meters (128 feet) and delivered weight is 18,000 kilograms (39,500 pounds). Packaging and deployment studies have shown that the telescope components can be delivered in two payloads of 240-inch I. D., or in a single advanced payload of 356-inch I. D.

6.0 EXPERIMENT DATA MANAGEMENT SYSTEM AND EXPERIMENT SEQUENCE FORMULATION

6.1 EXPERIMENT DATA MANAGEMENT SYSTEM

6.1.1 Description

The data management system basically consists of the entry of numerical and text data relative to a given scientific experiment in a format suitable for processing and sorting of the data on a digital computer system. Preliminary analysis of the operations involved and the extended lunar exploration summaries desired indicated that the program would resemble business-type computer operations, in which bookkeeping is a major factor, rather than scientific computer capabilities, in which solutions to mathematical equations are the objective. Consequently, the COBOL computer language and IBM 7010 computer were selected as the basic working tools of the experiment data management system.

6.1.2 Experiment Coding

Suitable codes were selected to allow scientific and engineering personnel to describe or to retrieve experiment information in terms of mission system constraints, subsystem support, and equipment performance requirements. These data have been stored on a series of standard IBM cards summarizing the essential characteristics of each experiment. A flexible computer data retrieval-documentation program has been developed which provides a wide variety of printed output displays for mission planners and systems engineers. These outputs have been organized to provide high-visibility data for systems analysis and management decision-making functions. The resultant data handling system also includes simple provisions for continual updating and maintenance of the data bank and for capacity to accommodate anticipated future growth.

An 11-digit number has been adopted to facilitate sorting of the data and identification of the experiments (Figure 6). The first three digits define the card type and card number (for multiple cards that must be sorted and printed in sequence). The remaining eight digits represent the basic experiment number by which all data cards can be correlated. The data have been organized so that either complete experiment descriptions or selected outputs can be retrieved at the discretion of the user. Seven types of data cards are being used. An important feature of the system is the ability to produce complete typewritten descriptions of the experiment and equipment,

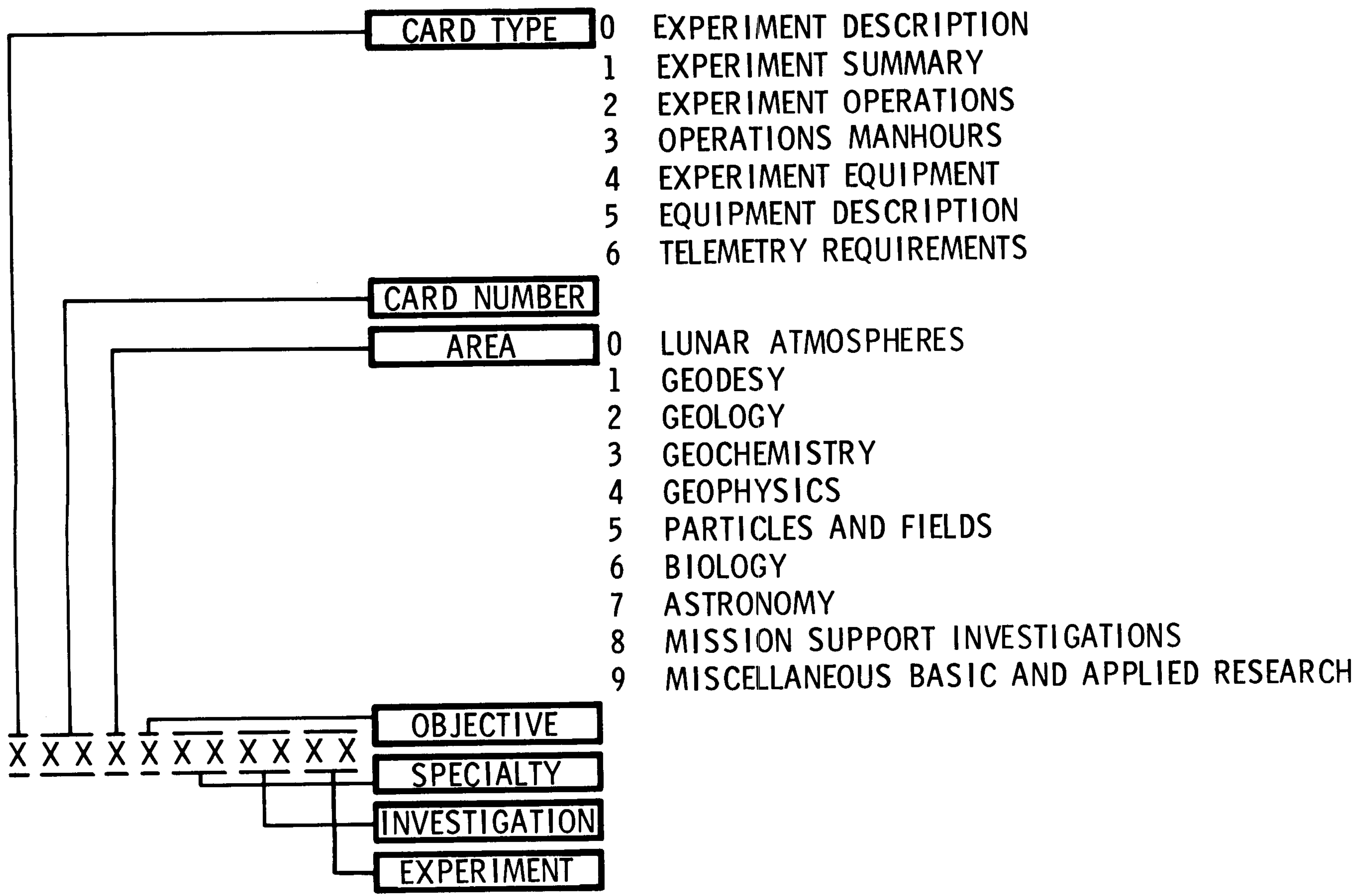

Figure 6. Experiment Identification and Data Organization

thereby providing documentation of important information that could not otherwise be encoded. As shown in Figure 6, all experiments have been organized into eight discipline areas of Fundamental Investigations, a single area of Mission Support Investigations, and an area of Miscellaneous Basic and Applied Research Investigations. Scientific objectives and major specialties have also been defined for each area to correlate related scientific investigations. The last four digits designate major investigations and experiments that support the investigations. Flexibility provided to accommodate anticipated future growth includes card information growth capacity, as in the Type-6 card, and the capability of incorporating new card types.

6.1.3 Card Description

The basic data entry cards were designated as Type-0 cards (experiment description), Type-1 cards (experiment summary), Type-2 cards (experiment operations), Type-3 cards (experiment man-hour categories), Type-4 cards (experiment equipment parameters), Type-5 cards (equipment description), and Type-6 cards (experiment telemetry requirements). The following paragraphs present brief descriptions of the data-entry cards along with a tabular decoded listing of typed information. The descriptions are based on a typical Particles and Fields experiment. In actual use, the field information is coded to reduce the number of cards to be processed and the amount of data storage facilities required. A typical encoded format is given in Figure 14.

6.1.3.1 Experiment Description

The Type-0 card (Figure 7) provides a written description of each experiment that generally describes the objective of the experiment and the phenomena to be measured. In addition, unique requirements or relationships are also provided that are difficult to encode.

6.1.3.2 Experiment Summary

The Type-1 card (Figure 8) is an experiment summary produced by the computer from information stored on other data cards. Primary emphasis is placed on data which affects mission system trade-offs. Therefore, data are included for experiment location, mobility requirements, exploration phasing, and chronological time. In addition, codes have been provided to define scientific importance and urgency for priority sequencing. Mission support requirements have been defined in terms of number of men, crew skill, man-hours, and equipment support parameters. Equipment leadtime

<u>SOLAR WIND INTERACTION WITH MOON AND GEOMAGNETOSPHERE.</u> MEASURE FLUX VERSUS MASS, CHARGE, ENERGY OF SOLAR WIND ELECTRONS, PROTONS. HEAVY NUCLEI AS FUNCTION OF HEIGHT ABOVE LUNAR SURFACE AND SUN ANGLE. WHEN EARTH AND SUN ARE NEAR SAME POSITION, SEARCH FOR GEOMAGNETICALLY TRAPPED ELECTRONS. EXAMINE PHOTOELECTRON-SOLAR WIND PLASMA SHEATH FROM FEW CENTIMETERS TO SEVERAL METERS ABOVE LUNAR SURFACE. CONDUCT SAME TIME, PLACES AS 53050101. CONDUCT AT LUNAR LOCAL SUNRISE OR SUNSET, NOON, MIDNIGHT. NEAR CENTER OF NEAR SIDE. IN FLAT OPEN AREA AND ON MOUNTAIN PEAK (AT LEAST 200 METERS).

Figure 7. Type-0 Card, Experiment Description

data are presented for the pacing item in the equipment set in terms of data for development status, development time, and earliest year available. Estimated development cost and first item cost are presented in the summary to provide budget guidelines for mission planners.

6.1.3.3 Experiment Operation

The Type-2 card (Figure 9) provides major information concerning experiment operations and mission support requirements. The major portion of this information is abstracted on the summary card. In addition, this card provides data to define experiment replication, gross communication requirements in terms of the total bits of information, bit rate, and the type of data link. Provisions have also been included on the operations card for compilation of a "relative experiment cost factor" which has not been defined as yet but which is based in general on the conversion of mass, volume, power, and man-hours into equivalent equipment dollars. These data, when available, will provide mission planners with guidelines for comparison of scientific investigations on an equivalent cost basis.

6.1.3.4 Operations Man-Hours

The Type-3 card (Figure 10) provides detailed estimates of astronaut man-hours to set up, operate, analyze, and tear down the instrumentation or equipment necessary to support an experiment. The man-hour estimates are differentiated for shirtsleeve and spacesuit conditions while the astronaut is operating from a roving vehicle or from a lunar base. These time estimates can be used by mission planners to evaluate logistic requirements for astronaut support systems. All of the times are given in terms of normal Earth shirtsleeve environment. To obtain actual lunar suit time, a "K" factor must be used. (Section 5.1 gives further explanation.) An average "K" factor of 3 is recommended, based on the best lunar-suit data presently available.

6.1.3.5 Experiment Equipment

The Type-4 card (Figure 11) is used to define the equipment requirements directly related to an experiment. In addition to the basic experiment number, all instruments or equipment have been identified by a six-digit numerical code based on the "Guide to Scientific Instruments" as developed by Science Magazine. This feature allows machine sorting to identify commonality and time-sharing of equipment to optimize mission logistics. The output format displays multiple cards for each item of different equipment. Data are provided concerning equipment location, parameter range and precision, and support-requirement parameters (mass, volume, power, data sample return, environmental constraints). These data cards are compiled cumulatively by the computer to produce the experiment summary.

DATA CATEGORIES	EXAMPLE INFORMATION
EXPERIMENT LOCATION	$\pm 10^0$ LAT SEE TYPE 'O' CARD POLAR ORBIT
MOBILITY REQUIREMENT	SHORT RANGE VEHICLE
EXPLORATION PHASE	EARLY EXPLORATION
CHRONOLOGICAL TIME	1972-1975
IMPORTANCE	TO ACCOMPLISH SCIENTIFIC GOALS
URGENCY	ESTABLISH FEASIBILITY OF SUBSEQUENT INVESTIGATIONS
NUMBER OF MEN	2
CREW SKILL	PARTICLES AND FIELDS ELECTRICAL ENGINEERING
EQUIPMENT MASS	5.2 KILOGRAMS
EQUIPMENT VOLUME (CUBIC METERS)	9.0×10^{-3} M^3

DATA CATEGORIES	EXAMPLE INFORMATION
TOTAL EQUIPMENT ENERGY	17,000 WATT-HOURS
PEAK POWER	4.0 WATTS
TOTAL MAN-HOURS	20.0 M/H
TRAVERSE MAN-HOURS	5.1 M/H
DEVELOPMENT STATUS	OPERATIONAL - NEEDS MODIFICATION
DEVELOPMENT TIME	1 YEAR
YEAR OF EARLIEST AVAILABILITY	1968
NONRECURRING COST	2,000,000
FIRST ITEM COST	400,000
TOTAL EARTH RETURNED (KILOGRAMS)	0.0 KILOGRAMS

Figure 8. Type-1 Card, Experiment Summary

DATA CATEGORIES	EXAMPLE INFORMATION
EXPERIMENT LOCATION	$\pm 10^0$ LAT SEE TYPE 'O' CARD POLAR ORBIT
MOBILITY REQUIREMENT	SHORT RANGE VEHICLE
EXPLORATION PHASE	EARLY EXPLORATION
CHRONOLOGICAL TIME	1972-1975
EXPERIMENT REFERENCE	LESA STUDY REPORT (REF 28)
FLIGHT STATUS	RECOMMEND IN NASA SUPPORT STUDY
IMPORTANCE	IMPORTANT TO ACCOMPLISHMENT OF SCIENTIFIC GOALS
URGENCY	ESTABLISH FEASIBILITY OF SUBSEQUENT INVESTIGATIONS
NUMBER OF MEN	2
CREW SKILL	PARTICLES AND FIELDS ELECTRICAL ENGINEERING

DATA CATEGORIES	EXAMPLE INFORMATION
M/H TRAVERSE SHIRT SLEEVE	1.1 HR
M/H TRAVERSE SPACE SUIT	4.0 HR
M/H BASE SHIRT SLEEVE	10.0 HR
M/H BASE SPACE SUIT	5.0 HR
REPETITIONS	3 TIMES
FREQUENCY OF PERFORMANCE	SEE TYPE 'O' CARD
EGRESSES	3 EXITS
CREW PARTICIPATION	MAJOR CREW PARTICIPATION
TOTAL DATA BITS	4.8×10^7
MAXIMUM DATA RATE	B/S 20.0 BITS PER SEC
DATA LINK	LUNAR SURFACE TO LUNAR ORBIT TO EARTH
EXPERIMENT COST FACTOR	
NUMBER OF ITEMS	3

Figure 9. Type-2 Card, Experiment Operations

DATA CATEGORIES	EXAMPLE INFORMATION
SETUP M/H TRAVERSE SHIRT	1.0×10^{-1} HR
OPERATION M/H TRAVERSE SHIRT	1.0 HR
ANALYSIS M/H TRAVERSE SHIRT	0.0 HR
TEAR DOWN M/H TRAVERSE SHIRT	0.0 HR
OPERATION M/H TRAVERSE SUIT	3.0 HR
SETUP M/H TRAVERSE SUIT	0.0 HR
ANALYSIS M/H TRAVERSE SUIT	0.0 HR
TEAR DOWN M/H TRAVERSE SUIT	1.0 HR
SETUP M/H BASE SHIRT	1.0 HR
OPERATION M/H BASE SHIRT	3.0 HR
ANALYSIS M/H BASE SHIRT	6.0 HR
TEAR DOWN M/H BASE SHIRT	0.0 HR
SETUP M/H BASE SUIT	3.0 HR
OPERATION M/H BASE SUIT	1.0 HR
ANALYSIS M/H TRAVERSE SUIT	0.0 HR
TEAR DOWN M/H TRAVERSE SUIT	1.0 HR

Figure 10. Type-3 Card, Operations Man-Hours

DATA CATEGORIES	EXAMPLE INFORMATION
EQUIPMENT ITEM	
EQUIPMENT NAME	FARADAY CUP
EQUIPMENT LOCATION	COMBINATIONS OF LOCATIONS EQUIPMENT MOVED DURING EXPERIMENT
PARAMETER	(SPECIALTY CODE)
PARAMETER RANGE	LOWER LIMIT 1.0×10^{-5} UPPER LIMIT 1.0×10^{-3} ACCURACY 2 DIGITS
EQUIPMENT MASS (KG)	0.46 KG
EQUIPMENT VOLUME (CUBIC METERS)	5.6×10^{-3}
AVERAGE POWER (WATTS)	4.0 WATTS
PEAK POWER (WATTS)	4.0 WATTS
EQUIPMENT OPERATING TIME (HR)	2800 HR
AVERAGE DATA RATE BITS/SEC	20.0

DATA CATEGORIES	EXAMPLE INFORMATION
TYPE OF DATA	DIGITAL TELEMETRY STORED DATA
MAX DATA RATE BITS/SEC	20.0
REAL TIME DATA RATES BITS/SEC	20.0
EARTH RETURN MASS (KG)	0.0 KG
PACKAGING REQMTS	NO SPECIAL REQUIREMENTS
STORAGE REQMTS	NO SPECIAL REQUIREMENTS
ENVIRONMENTAL REQMTS	LUNAR DUST EXPOSURE
DEVELOPMENT STATUS	OPERATIONAL - NEEDS MODIFICATION
DEVELOPMENT TIME	1 YEAR
YEAR OF EARLIEST AVAILABILITY	1968
NONRECURRING COST	\$2,000,000
FIRST ITEM COST	\$400,000

Figure 11. Type-4 Card, Experiment Equipment

FARADAY CUP PLASMA SPECTROMETER. WITH POWER CONVERTER, DATE ENCODER. COLLAPSIBLE POLE TO VARY HEIGHT FROM 10 CENTIMETERS TO 10 METERS. POLE ELECTRICALLY INSULATED WITH OPTION TO CONNECT TO GROUND. ONE CUP AT BASE IN FLAT AREA (2000 HOURS). ONE ON TRAVERSE AT MOUNTAIN PEAK (800 HOURS). POLE MASS AND VOLUME EXTRA.

Figure 12. Type-5 Card, Equipment Description

DATA CATEGORIES	EXAMPLE INFORMATION
EQUIPMENT NUMBER	30921
PARAMETER	(SPECIALTY CODE)
PARAMETER NAME	KINETIC ENERGY
PARAMETER RANGE	LOWER LIMIT 1.0×10^{-5} UPPER LIMIT 1.0×10^{-3} ACCURACY 2 DIGITS
EXPERIMENT DURATION	2,800 HR
DATA LINK	LUNAR SURFACE TO LUNAR SURFACE
STORAGE	YES
PERIODIC READOUT	COLLECTION 6 MIN READOUT 90 SEC
EVENT	VARYING PERIODIC
TYPE DATA	DIGITAL
SIGNAL CONDITIONING	AMPLIFICATION PLUS CONVERSION
OUTPUT DURATION	2,800 HR
ANALOG FREQUENCY	NOT APPLICABLE
ANALOG ACCURACY	NOT APPLICABLE
BITS RESOLUTION	NOT APPLICABLE
DIGITAL OUTPUT	SERIAL
NUMBER OF BITS	15 BITS PER WORD
BIT RATE	200 BITS PER SEC
NUMBER OF COMMUTATED INPUTS	NOT APPLICABLE

Figure 13. Type-6 Card, Experiment Telemetry Requirements

6.1.3.6 Equipment Description

The Type-5 card (Figure 12) is essentially a supplement that provides a written description of the equipment, with up to 99 cards available to define the requirements for new equipment or data not otherwise encodable. The first card in the series contains development status and cost data for the particular instrument or item of equipment.

6.1.3.7 Equipment Telemetry Requirements

The Type-6 (Figure 13) card represents a capability of the experiment data management system to provide detailed information for specific subsystems that are critical for experiment support requirements of the overall base system. It contains telemetry requirements information relating to baseline equipment used in a given lunar experiment if such equipment has a distinct telemetry output. The same equipment may be used in several experiments; however, only one entry is currently provided. An equipment commonality matrix provided in the report may be consulted or the IBM cards may be sorted by equipment number to aid in approximating the total telemetry requirements for an experiment. It should be noted that the information currently provided on these cards is very preliminary in nature due to the development status of the equipment.

6.1.3.8 Printout Format

Figure 14 shows the actual printout format for Type-0 cards thru Type-6 cards. The printouts are presented in Volume 5, Appendix B, of this report.

6.1.4 Capability of Data Management System

The SMS-ELE data management system can be used in many ways after the required experiment information is available for a variety of proposed space mission experiments.

6.1.4.1 Data Management System Updating

The revision or updating procedure is a feature of the data management system which has already been used in the study. This feature allows changes of data on the computer program master tape without the necessity of rerunning the entire punched card input file. Corrected card files can be generated directly from the updated tape when the punched card file revision is desirable. In the present study, this data file is on the order of 8000 punched cards to describe the 340 experiments compiled in this study.

TYPE -0

EXPERIMENT DESCRIPTION

	CD TY	EXPERIMENT NUMBER: CP NO	AREA	OBJT	SPEC	INVS	EXPT	EXPERIMENT DESCRIPTION
ACTIVITY	X	XX	X	X	XX	XX	XX	← →
CARD COLS	1	2 3	4	5	6 7	8 9	10 11	12 – 80

TYPE -1

EXPERIMENT SUMMARY

	CD TY	EXPERIMENT NUMBER: CD NO	AREA	OBJT	SPEC	INVS	EXPT	EXPERIMENT TITLE	EXPT LOCA	MOB REQ	PHASE	CHRON TIME	IMPORT	URGNCY	NO MEN	CREW SKILL	EQPT MASS KG	EQPT VOL CU M	TOTL EQPT ENGY KWH	PEAK POWR WATT	TOTL MAN-HRS	TRVRS MAN-HOURS	DEV STAT	DEV TIME	YEAR AVAIL	NREC COST	FIRST COST	TOTL ERTH RETD MASS KG
ACTIVITY	X	XX	X	X	XX	XX	XX	← →	XXX	X	X	XXX	X	X	X	XX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	X	X	XX	XX	XX	XXXX
CARD COLS	1	2 3	4	5	6 7	8 9	10 11	12 – 31	32 33 34	35	36	37 38 39	40	41	42	43 44	45 46 47 48	49 50 51 52	53 54 55 56	57 58 59 60	61 62 63 64	65 66 67 68	69	70	71 72	73 74	75 76	77 78 79 80

Figure 14a. Data Printout Format

TYPE -2

EXPERIMENT OPERATIONS

	CD TY	CD NO	AREA	EXPERIMENT NUMBER OBJT	SPEC	INVS	EXPT	EXPERIMENT TITLE	EXPT LOCA	MOBREQ	PHASE	CHRON TIME	EXP REF	FLTSTA	IMPORT	URGNCY	NO MEN	S CK RIEL WL	TRAVERSE MAN-HOURS SS HL RE TV	SS PU AI CT	BASE SS HL RE TV	SS PU AI CT	REPETN	FRQNCY	EGRESS	PA CR RT EI WC	TOTAL DATA BITS	L A S	MAX DATA RATE B/S	DL AI TA	L I N K	EXPT COST	NO	ITEMS
ACTIVITY	X	XX	X	X	XX	XX	XX	← →	XXX	X	X	XXX	XX	X	X	X	X	XX X	XX	XXX	XXX	XXX	XX	X	X	X	XXX	X	XXXX	X	X	XXXX	X	X
CARD COLS	1	2 3	4	5	6 7	8 9	10 11	12 – 31	32 33 34	35	36	37 38 39	40 41	42	43	44	45	46 47 48	49 50	51 52 53	54 55 56	57 58 59	60 61	62	63	64	65 66 67	68	69 70 71 72	73	74	75 76 77 78	79	80

TYPE -3

OPERATIONS MAN-HOURS

	CD TY	CD NO	AREA	EXPERIMENT NUMBER OBJT	SPEC	INVS	EXPT	TRAVERSE SET-UP	SHIRTSLEEVE OPERATION	SHIRTSLEEVE ANALYSIS	TEAR DOWN	SET-UP	SPACESUIT OPERATION	SPACESUIT ANALYSIS	TEAR DOWN	BASE SET-UP	SHIRTSLEEVE OPERATION	SHIRTSLEEVE ANALYSIS	TEAR DOWN	SET-UP	SPACESUIT OPERATION	SPACESUIT ANALYSIS	TEAR DOWN
ACTIVITY	X	XX	X	X	XX	XX	XX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
CARD COLS	1	2 3	4	5	6 7	8 9	10 11	12 13 14 15	16 17 18 19	20 21 22 23	24 25 26 27	28 29 30 31	32 33 34 35	36 37 38 39	40 41 42 43	44 45 46 47	48 49 50 51	52 53 54 55	56 57 58 59	60 61 62 63	64 65 66 67	68 69 70 71	72 73 74 75

Figure 14b. Data Printout Format (Cont)

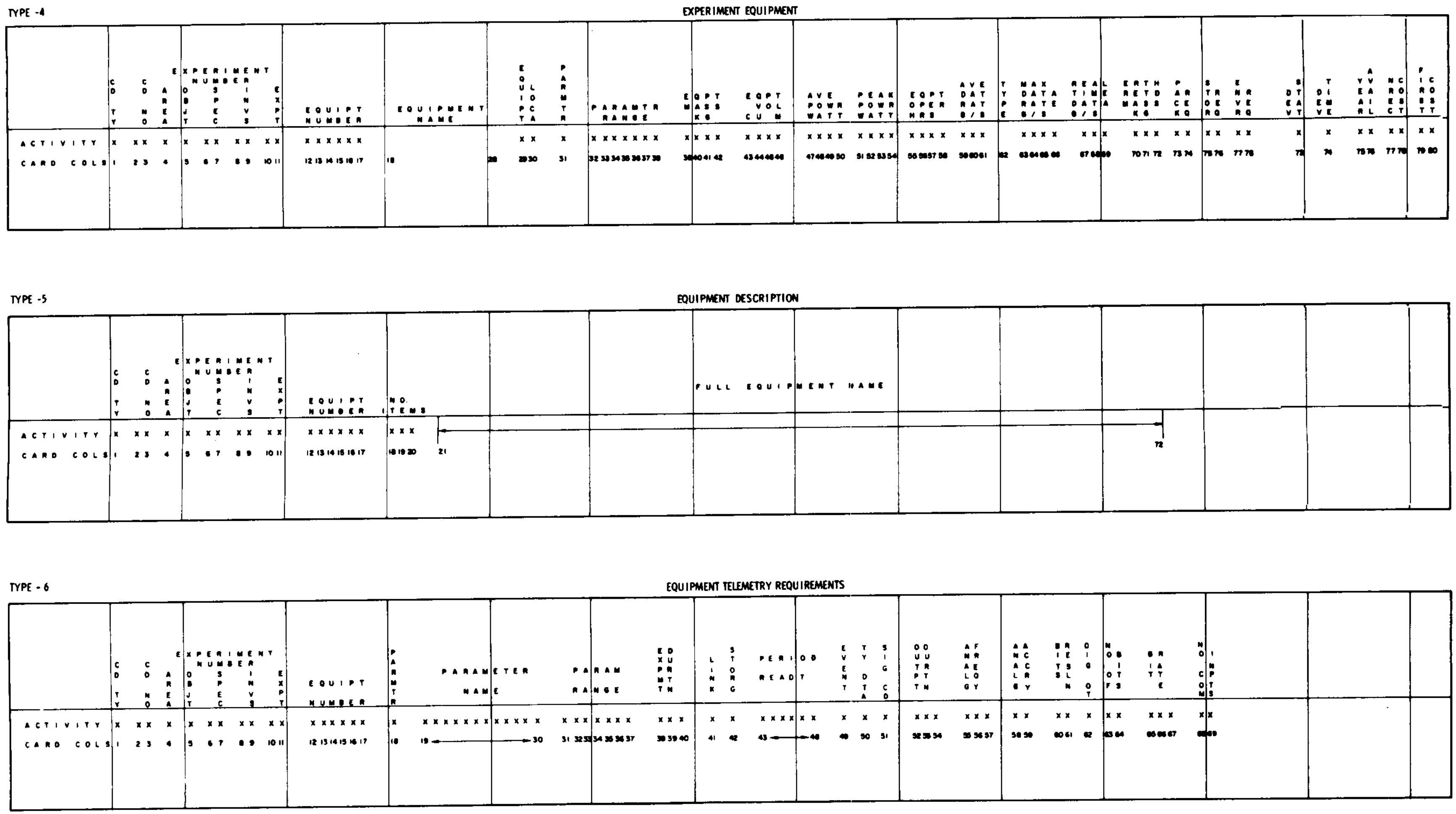

Figure 14c. Data Prinout Format (Cont)

Revising data within an existing data card is accomplished simply by identifying the experiment and card number and then entering the revised data on only the data field of the card being changed. All of the updating procedures require processing of a new punched card for each addition or change to be accomplished, but the amount of data coding and processing is kept to a minimum by the developed procedures. The correction cards are simply added to the next run of additions to the master data tape; the computer searches the tape for the card identification number and transfers the desired corrections to the tape which is then ready for use on the next program run.

The deletion of an experiment requires manual removal of the applicable data input cards from the input card decks and then reconstruction of the data input tape.

6.1.4.2 Miscellaneous Uses - Data Management System

In addition to those programs directly utilized in this study, auxiliary programs can be written to search, select, and compile data in a variety of ways. Several of these operations and their results are illustrated in the Detailed Technical Report (Volume 3). In addition, any of the data fields can be made the basis for special listings. For example, the mobility, requirement column of either the Type-1 summary card or the Type-2 operations card, can be made the basis for a search and listing to identify all the proposed lunar experiments for which the use of a small roving vehicle was recommended. With the capability to search, select, and compile data, inherent in the data management system, the mission planner is provided with the implements necessary to introduce specific system capability with respect to scientific missions. Specifically, he may apply a constraint for every data field represented in the data management system. By applying sequential card sorting, the planner may utilize any combination of constraints. In this manner a scientific mission capability of a given system can be defined if the system constraints associated with the specific system or concept can be defined.

6.1.4.3 Potential Applications

The potential applications of the system can best be illustrated by citing the growth of the computer data retrieval program to its present configuration. As originally conceived, the program was primarily intended for use in developing system and operation-support requirements tradeoffs for lunar exploration mission and system concepts. This need was satisfied initially by the Type-1 card information; however, when more information was needed concerning the activities of the lunar base crew, Type-2 and -3 cards were added. At this point, the information satisfied the immediate requirements, but to be most effective, such a computer data retrieval program should also be able to accommodate the mission planner's future need for information. This means that the data retrieval program must be at least one generation of study activity ahead of the system studies. Therefore, Information Card Types-4, -5, and -6 were added. The near-future expansion requirements could include detailed subsystem information regarding life support subsystems, lunar spacesuit, power, mobility, etc. These requirements can be satisfied by the addition of Card Types -7, -8, etc.

6.1.4.4 Conclusion

The most significant result of the computer data retrieval program is the establishment of a flexible and expandable information storage and retrieval system that can be used as a management tool for lunar exploration and mission support planning. This system is dynamic in nature; it has the ability to grow and change and, thereby, adapt to the future requirements relating to the scientific exploration of the Moon.

6.2 EXPERIMENT SEQUENCING

To better understand the scientific mission support needs and to aid in the development of future lunar exploration systems, experiment sequences were formulated utilizing the information contained in the experiment data management system. (See Volume 4, Appendix A, Experiment Sequences.) Lunar exploration planning requires the organization of scientific experiments and investigations into logical order and groups so that maximum advantage can be taken of the amount of equipment and man-hours available on the lunar surface during any particular period. For the results to be of maximum use, mission planning must consider individual experiments and their related support requirements, as well as the relationship between experiments within and across various scientific disciplines, taking advantage of common equipment use or similar mission support requirements for a more efficient operation.

Four sequences of experiments were generated during the study: Discipline Sequences, Mission Support Sequences, Exploration Phase Sequences, and Composite Sequences. Figure 15 illustrates the experiment sequence formulation.

6.2.1 Discipline Sequences

The Discipline Sequences order experiments within a given discipline, in terms of a logical sequence of scientific accomplishment. These sequences were compiled within the guidelines developed by the scientific community

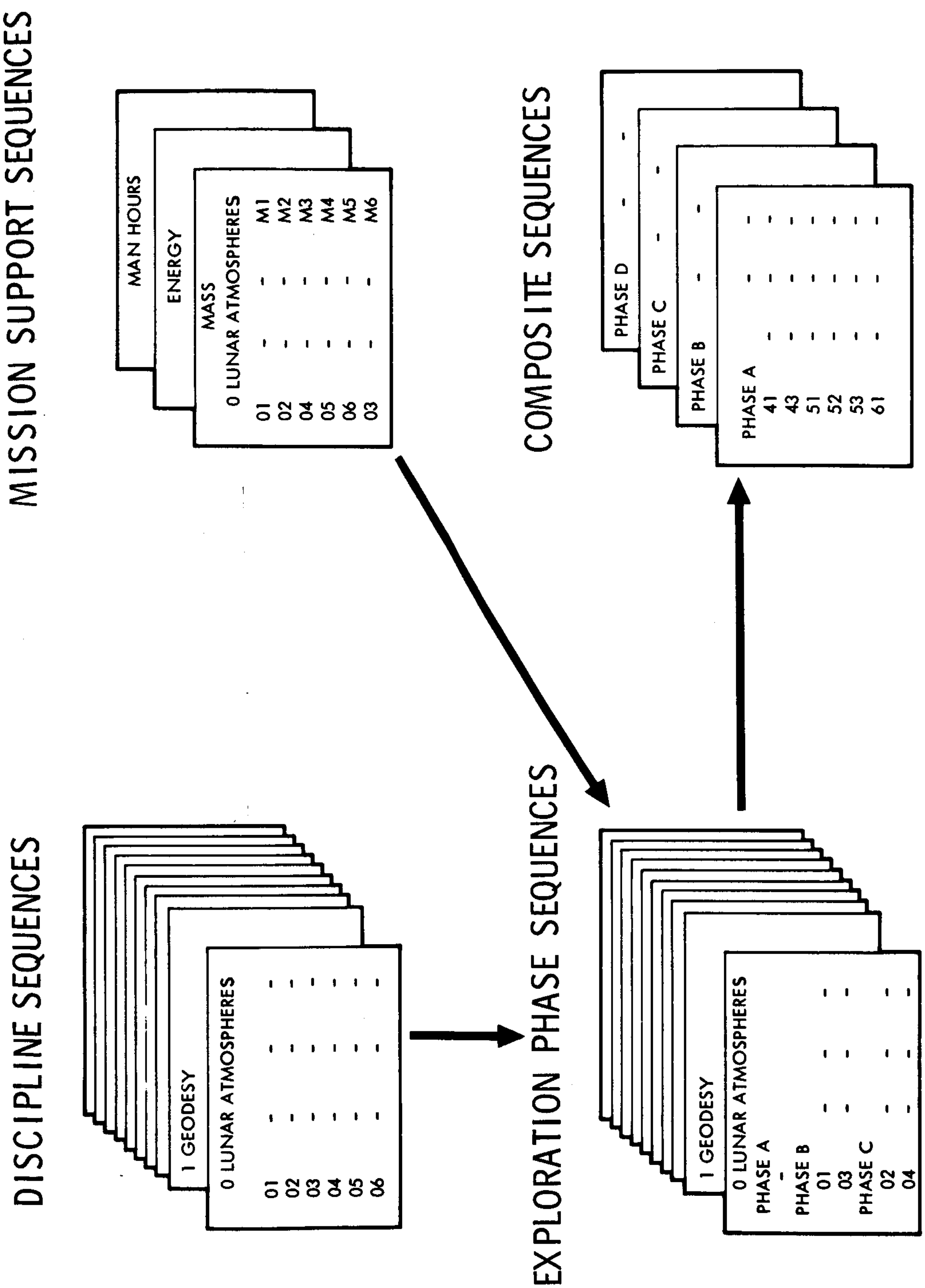

Figure 15. Experiment Sequences Schematic

and by NASA. The Discipline Sequence formed a basis upon which the succeeding sequences were developed. The location of an experiment within a discipline sequence is referred to as the order of the experiment.

6.2.2 Mission Support Sequences

The Mission Support Sequences were formulated by listing experiments within a given discipline area by ascending mission support requirements, such as equipment mass, energy, and man-hours. They were developed not only as an aid to the mission planner but as a basis for further sequence development. These sequences can be used to determine various combinations of mass to make up a payload, various energy combinations that are within the capability of a given energy source, and groupings of experiments performed within a specified stay time on the lunar surface. They were also used to investigate the continuity of mission support parameters and determine exploration phasing criteria. Mission Support Sequences are presented in Volume 4, Appendix B.

6.2.3 Exploration Phase Sequences

Exploration Phase Sequences were formulated to identify logical phasing of lunar exploration by scientific discipline and to identify the support capability requirements of each phase. Exploration Phase Sequences are presented in Volume 4 of this report.

A methodology requiring two iterations, utilizing the Discipline Sequences with the additional mission support considerations, was employed to develop the Exploration Phase Sequences. Mission support requirements, such as mass and energy, were plotted versus experiment sequencing as determined by the Discipline Sequences to ascertain continuity of these parameters and assess potential phasing criteria for each discipline. This is illustrated by Figure 16, which is an actual plot related to the Particles and Fields discipline area. If a point was found that was apparently out of trend, indicating requirements logically fitting later in the order, the experiment and related subsequent experiments were reviewed. If the experiment had no other experiment depending on it and appeared to be independent within the Discipline Sequence, the ordering was modified so that the experiment took place at a more logical point with respect to mission support requirements. In some cases, the experiment could not be moved without making it meaningless or without moving a whole series of subsequent experiments. In these cases, the analysis usually indicated whether the experiment should start a new phase with the capability to support it, or whether the experiment should perhaps be modified to reduce its requirement for support. Orbital experiments were kept in their original sequence in all cases. The analysis of the diagrams of the mission support requirements of the Discipline Sequences

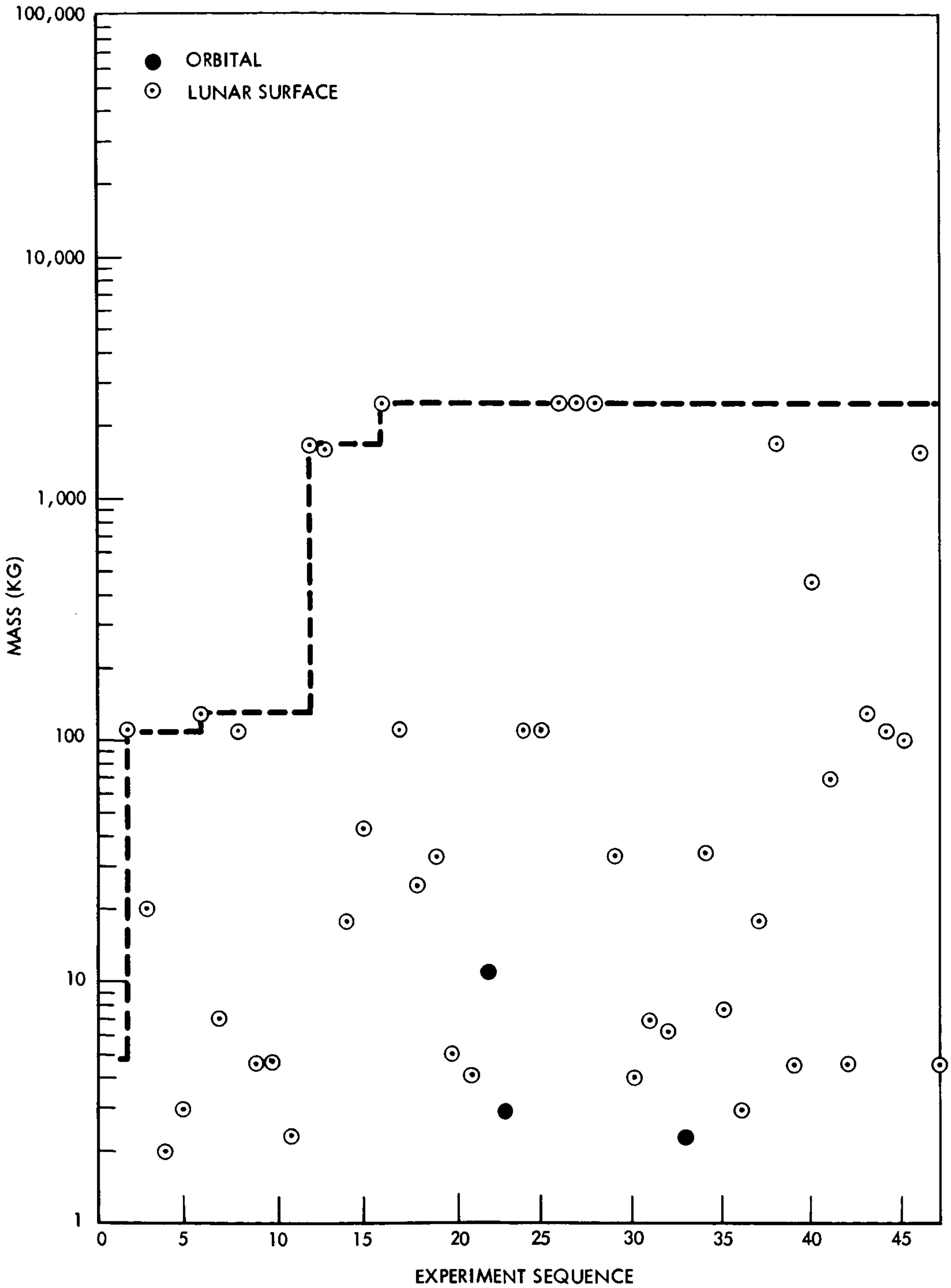

Figure 16. Mass Requirements Versus Experiment Sequence - Discipline Area 5, Particles and Fields

yields the first visualization of exploration phased activity. This analysis provided insight into levels of system support requirements. In some cases, several levels of support requirements were indicated. The breaks in levels are indicative of a change in support requirements, indicating a possible upgrading and modification of existing systems or the possibility of a new system for the particular discipline under consideration.

The primary phasing criteria established for the first iteration were mass and energy. Figure 17 represents the results of the first iteration for the energy parameter. This figure was obtained by superimposing energy requirements plotted versus experiment sequencing for each discipline area (similar to Figure 16). Natural breaks or plateaus were then identified as phase breaks. The second iteration was based on general criteria including man-hours, mobility requirements, power packages, and number of men. The two iterations resulted in the definition of the exploration phases and the assignment of the experiments of each discipline to the phases.

As a result of this sequencing effort, five exploration phases (A, B, C, D, and E) were identified, and are summarized in Table 8. Phase A is generally consistent with the Apollo initial lunar landings. Phase B appears to be within the general system capability of the Apollo Applications Program (AAP) as it is now visualized and can be considered as early lunar exploration. Phase C experiment requirements appear to warrant lunar surface stay times on the order of several months, with extended mobility capability, and represents a transition to extended lunar exploration. Phase D experiments primarily require stay times of about 6 months to one year. For Phase E experiments, stay times of several years (2 to 10), appear to be desirable. These latter two phases represented extended lunar exploration and exploitation.

The number of experiments within each phase is summarized by discipline area in Table 9. The increasing capability of each phase is illustrated in terms of mass and energy.

By the end of Phase B, most discipline areas have reached their peak rate of experiment performance. Sixty percent of the lunar-oriented experiments can be accomplished. Phase C provides the capability of performing almost eighty percent of the experiments by number. The experiments requiring Phase D and E capabilities are the long-term experiments of Geophysics, Particles and Fields, and the Astronomy experiments. The Astronomy experiments include ultimately a large telescope with an aperture on the order of 100 inches. Such a telescope requires logistic payload capabilities of approximately 40,000 pounds, if it is desired to utilize only one payload. However, the telescope may be shipped to the lunar surface in two smaller payloads and deployed on the lunar surface during Phase D.

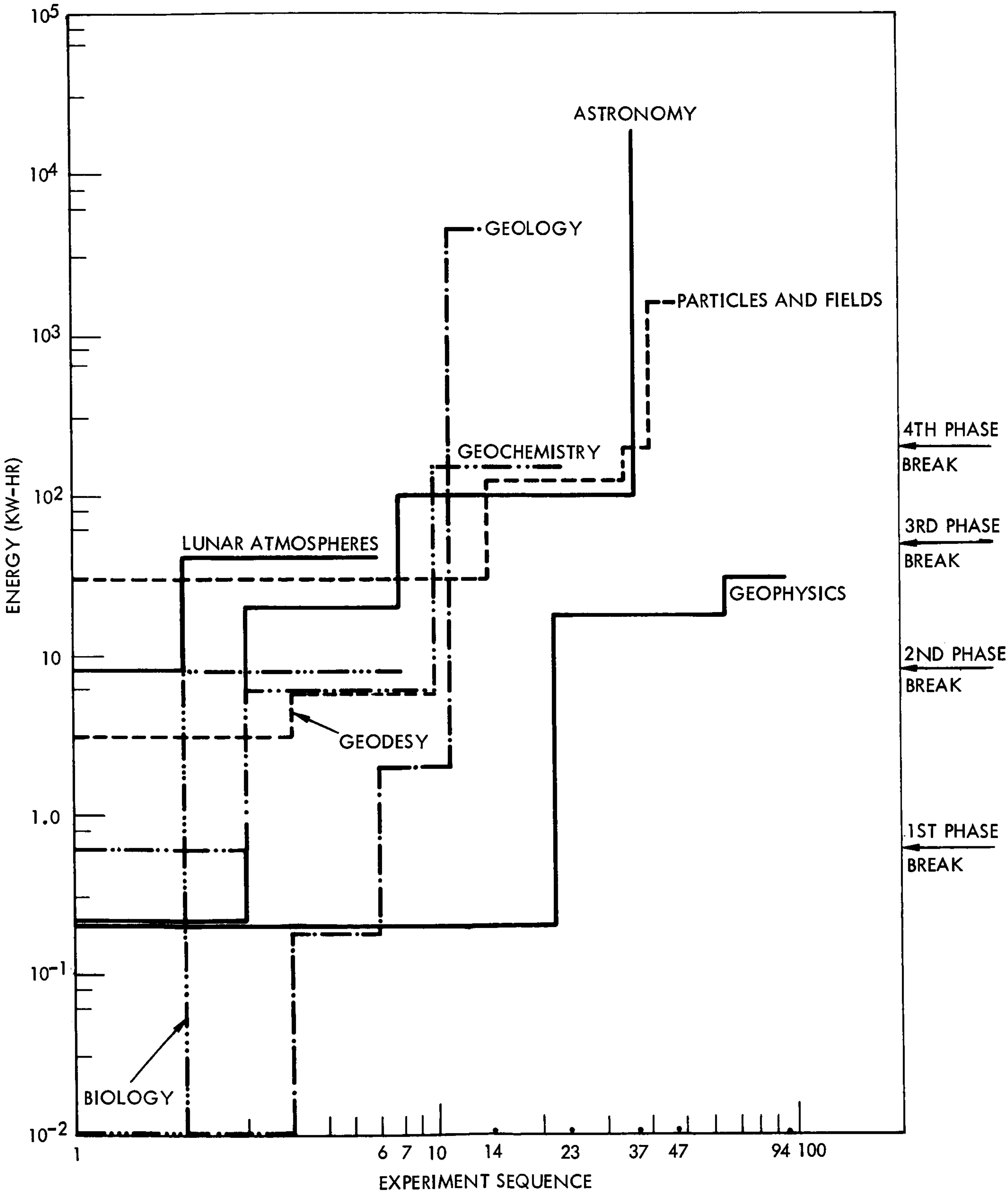

Figure 17. Energy Requirements Versus Experiment Sequence, Discipline Areas 0 Through 7

Table 8. Phases of Extended Lunar Exploration

Phase	Characteristic Name	Approximate Lunar Stay Time (days)	Maximum Energy Per Experiment (kw - hrs.)	Maximum Mass Per Experiment (kg)	Average Man-Hours Per Experiment	Characteristic Mobility Mode
A	Apollo	3	0.6 *	20	5	Walking
B	Apollo Applications Program	Less than 30	8.0 **	150	20***	Short-range roving vehicle (LSSM-type)
C	Extended Exploration	90	50	500	120	Long-range roving vehicle
D		180	200	4000	210	
E		Greater than 180	Greater than 200	Greater than 4000	640	

*Reflects energy requirements during manned missions. For experiments of long duration, exceeding the manned mission time, an ALSEP energy source is assumed to exist with a power output of at least 56 watts supplied for a period of one year. (See Section 4.4)

**Reflects energy requirements during manned missions. For experiments of longer duration, exceeding the manned mission time, an ESS energy source is assumed to exist (one 100-watt central and three 10-watt satellite RTG units), operative for a period of one year. (See Section 4.4)

***Initial man-hour requirements on the following six early-exploration experiments were in excess of reasonable estimates on available astronaut time on the lunar surface during Phase B. Subsequent review of these experiments by the NAA scientific staff resulted in establishing minimum man-hour requirements that were judged sufficient to yield significant scientific results.

	Desirable Man-Hour Estimates	Minimum Man-Hour Estimates
61040102, Evidence of Existing Life	270	22
71010101, Lunar Environmental Test	310	60
72010102, High Resolution Photography	320	60
72010104, Low Dispersion Spectroscopy	310	60
72010205, Sky Survey	920	60
72010206, Variable Brightness	500	60

The original man-hour estimates on the above experiments were not changed as they represent scientifically desirable times.

Table 9. Experiment Distribution Based on Mass and Energy Requirements Combined

Phase	Mass (kg)	Energy (kw-hrs)	Lunar Atmospheres	Geodesy	Geology	Geochemistry	Geophysics	Particles and Fields	Biology	Astronomy	Mission Support Investigations	Miscellaneous Basic and Applied Research	Total
			Number of Experiments										
Orbital	1.0 to 700	0 to 150	0	2	2	4	10	3	0	3	6	0	30
A	20 or less	0.6 or less *	2	0	3	4	12	2	2	0	3	0	28
B	21 to 150	0.61 to 8.0 **	2	3	6	15	40	12	2	11	52	2	145
C	151 to 500	8.1 to 50	2	2	2	0	22	11	3	7	20	0	69
D	501 to 4000	51 to 200	0	0	0	0	8	16	0	9	11	6	50
E	Greater than 4000	Greater than 200	0	0	1	0	2	3	0	7	0	1	14
Total			6	7	14	23	94	47	7	37	92†	9	336†

†4 Mission support experiments are not listed here. They are correlative in nature, utilizing data from other experiments and require no lunar surface support (See Section 4 Table 5.)

*Reflects energy requirements during manned missions. For experiments of long duration, exceeding the manned mission time, an ALSEP energy source is assumed to exist with a power output of at least 56 watts supplied for a period of one year.

**Reflects energy requirements during manned missions. For experiments of longer duration, exceeding the manned mission time, an ESS energy source is assumed to exist (one 100-watt central and three 10-watt satellite RTG units), operative for a period of one year.

6.2.4 Composite Sequence Formulation and Evolutionary Experiment Programs

The Composite Sequences were established in two steps of increasing operational detail. The experiments of each Exploration Phase were grouped according to the following four experiment - location categories: "in lunar orbit," "on traverse," "at base," and "both base and traverse." Within each of these four categories, the experiments were further sorted into subgroups according to common key operational factors, including among others the following operations and subsystems: "drilling," "sampling," "emplace and monitor," "telescope," "laboratory-analytical," "radio and radar," etc.

If several experiments from the same discipline area were associated with a given key operational factor, they were ordered with respect to each other according to the corresponding Discipline Sequences. No attempt was made to establish experiment priorities across disciplines within each of these subgroups.

Key experiments included in Discipline Areas 8 and 9 were identified for each common factor group. These experiments, while not fundamental in nature, need to be performed to obtain data essential for the development of more complex equipment required by experiments in the later phases. They should be performed sufficiently early to permit adequate lead times for possible modification of proposed equipment and/or techniques.

By examining the evolution of experiments associated with a common factor across several phases it is possible to obtain an integrated overview of an experimental program.

The groupings of experiments by common operational factors greatly facilitates mission planning, as it enables the formulation of convenient packages of experiments that can be readily assembled into missions. These groupings are presented in Volumes 3 and 4 of the final report.

7.0 EARTH RESOURCE REQUIREMENTS, CONTINGENCY PLANNING, AND EXPLORATION PROGRAM FACTORS

7.1 EARTH-BASED SCIENTIFIC SUPPORT REQUIREMENTS

Earth support requirements of extended lunar exploration relate to all Earth operations that support the missions and include a spectrum from logistics to flight control. This study has restricted its scope to the scientific support requirements necessary to analyze returned data. The primary requirements considered were for scientists, technicians, and laboratories.

Sensitivity analysis indicated that the requirement for scientists was most critical to the experiments and their returned data and, consequently, to the accomplishment of scientific objectives. Estimates and forecasts of scientists were made as conservative as possible because of unknown factors such as war possibility; major economic change; international plans for lunar exploration; military plans for lunar utilization; concurrent NASA plans; scientific advancements that may radically change our knowledge of the lunar surface; quantum increases in engineering and technology capability that may make obsolete our current vehicle, logistics, communications and transportation concepts, or the number of replications of experiments presently considered to be sufficient for mission and total investigation accomplishment.

A wide variety of assumptions was employed. One of these was that all raw instrument data will be telemetered to Earth for analysis. Other typical assumptions dealt with the number of samples per pound of Earth-returned mass (related to experimental data) and the time to analyze and report each sample, the number of repetitions of experiments per mission per evaluation phase, and an estimate of the time span which the lunar program of interest here would cover.

Scientist requirements and availability were forecast, indicating a shortage at the beginning of the program which would tend to increase throughout the first three phases. This shortage could create a backlog of data that might jeopardize the program. The long training needed to develop scientists, create interest, and channel activities makes this time critical.

Technicians required to support the scientists include microscope analysts, chemical laboratory assistants, computer programmers, etc. The short training requirement of technicians will allow development of a sufficient number with minimum lead time and cost.

Engineer availability is expected to be sufficient to support the requirements associated with the scientific and engineering experimentation.

Laboratory requirements were developed for each phase. This development shows a requirement for more than seven million square feet of new laboratory space by the end of Phase D to support extended lunar exploration. At the maximum laboratory costs and development times, the impact would be small compared with the program costs and scientist development time. It would appear that if the program can be financed, the laboratories can be also; and if scientists are trained and available, the laboratories should be available.

The total Earth support required for extended lunar exploration includes the items analyzed in this report but is not limited to the evaluation of return data. It imposes scientific and technological requirements that hold profound implications in the socioeconomic field. For these reasons, additional effort should be expended for a full synthesis of the requirements relative to budget, economics, politics, and geopolitical considerations.

7.2 CONTINGENCY PLANNING

The experiments presented in this report are based on the current understanding of the Moon. Unexpected phenomena will most certainly be discovered which may disprove present major theories and aid in the formulation and the proving of new theories. These possibilities are defined as contingencies. It is beyond the scope of this study to analyze the possibilities for various contingencies since by their nature they are unexpected. However, mission planners must be able to respond quickly and positively to unexpected phenomena. Therefore in the formulation of the experiment data management system and the methods by which the experiment sequencers were put together allowance was made for contingency possibilities.

Three types of contingencies that could substantially alter the lunar exploration experiments or their sequences were examined. These were: 1) those that would change the sequencing of experiments, 2) those that would require a change in emphasis among the list of experiments and 3) those that would alter the capability of proposed installations on the lunar surface. Table 10 presents a list of typical contingency examples and their probable effect on the lunar exploration program.

7.3 RELATION TO PLANETARY EXPLORATION

The National space program already incorporates phased development of Earth orbital, lunar, and interplanetary exploration capabilities. Each phase of the program should be expected to utilize, to the greatest extent feasible, the scientific, technological, hardware, operations and other support capabilities developed in the preceding programs. Continued

Table 10. Scientific/Technological Contingencies

Event	Probable or Ramifications		
	Favorable	Unfavorable	Other
• Finding water	• Life support, fuels generation, reduced payloads required		• Change target sites
• Ores, minerals	• Accelerated interest, support more missions	• Claims and competition	
• Biota	• Stimulated scientific and public support	• Possible dangerous forms back contamination	• More handling care
• Seismic		• Poor for astronomy experiments	• Modify experiments. May change experiment program
• Volcanic	• Favorable chem strut		
	• Might accelerate program		
• Communications from space	• Heightened interest/support		• May change experiment program
• Reduced gravity		• Possible decreased work capability	
• Night operations	• Favorable heat rejection	• Limited visibility	• Effect on staytime
		• Extreme cold	
• Pyrophorics		• Increased hazards slowed accomplishments	
		• Changed designs	

*Lunar orb-rendezvous

application of this step-by-step development through advanced lunar and interplanetary missions will contribute to the continuation of the high degree of success achieved in the manned missions flown to date. As a consequence, manned planetary exploration may become the next major space goal after lunar exploration.

The development of space science and technology for manned Earth orbital, lunar orbital, and lunar surface exploration missions is expected to bring experiment equipment and support system capabilities generally within reach of planetary mission requirements. In many surface exploration equipments, the more severe thermal-vacuum lunar environment may well be governing. In supporting systems, commonality of support requirements for extended-duration lunar exploration and manned planetary exploration missions encourages consideration of commonality of technology and hardware.

Review of scientific objectives of planetary missions shows broad similarities with those of lunar exploration. Table 11 lists typical scientific objectives of planetary flyby missions. This list was derived from a compilation prepared in an earlier flyby study (Reference 8); the compilation was based on objectives presented to Congress by NASA, suggestions by members of the scientific community, and results of other studies of interplanetary missions.

Comparison of planetary missions with lunar scientific experiments and investigations compiled in this study indicates that scientific experiment objectives, experiment techniques, and equipment developed for and proven in extended lunar exploration will provide major advantages and support to planetary exploration.

The life sciences will be a priority area in planetary exploration. All disciplines, i.e., exobiology, biomedical and human factors, and life support, are critical to mission success. In lunar mission support, the "Biological Contamination of Lunar Soil" investigation provides an assessment of planetary life detection techniques and investigates survivability of Earth organisms. The lunar applied biomedical and human factors investigations generally concern astronaut performance in a reduced gravity environment and astronaut physiological and psychological adaptation in prolonged missions, which are highly significant considerations for manned planetary missions. Life support applied research is directed toward the advancement of closed ecological system technology and assessment of the biological effects of prolonged exposure to the lunar environment. Consideration should be given in the detailed formulation of these investigations to the assurance of major applicability, as well as to planetary mission support requirements.

Table 11. Typical Scientific Objectives of Planetary Flyby Missions
(Reference 8)

Discipline Area	Scientific Objectives (Typical)
Geodesy	Figure of planet Surface maps Gravitational field
Geology and Geochemistry	Surface relief and photogeology Surface physical state Surface composition
Geophysics	Magnetic field Trapped radiation spectrum Effect of phobos on magnetosphere Heat balance Surface temperature Surface radioactivity Soil thermal and electrical conductivity Seismic activity Meteoroid mass, velocity, and composition
Atmosphere	Atmospheric composition Atmospheric pressure, density, and temperature Sound velocity Ion, electron density
Particles and Fields	Solar wind protons Solar high-energy protons, electrons, alphas Galactic protons
Biology	Life forms
Astronomy	Planetary radio emission Radio reflectivity
Mars Satellites	Satellite figures, rotation periods Satellite relief, surface temperatures
Asteroids	Asteroid figures, rotation periods Asteroid relief, surface temperature

Lunar investigations in support of the geosciences will also support Mars exploration technology and, in some cases, probably will have Mars mission counterparts. "Lunar Geological-Geochemical Sample Cassettes," "Explosive Energy Coupling in Lunar Materials and Calibration of Remote-Sensing Techniques," are examples of these investigations.

From the standpoint of technology, many of the Mission Support Investigations defined in this study will provide direct or indirect support to hardware development and mission planning for planetary exploration. For example, certification of proposed manned landing sites will have to be performed from Mars orbit. Therefore, correlation with the "Topography of Proposed AAP LEM Landing Sites" investigation is indicated. Experiment techniques and equipment for the "Engineering Properties of the Lunar Surface" investigation appear applicable to similar necessary investigations of the surface of Mars.

Manned exploration missions to Mars will nominally be on the order of 400 to 700 days duration. A major portion of this time will be spent in transfer from Earth to Mars and the return transfer from Mars to Earth. Support of the crew during these periods will be centered in a mission module of the interplanetary spacecraft. A crew of six has been considered nominal for this mission. For manned exploration performed from Mars, a Mars excursion module and other exploration support equipment will be utilized. Surface exploration, to be most effective, will require roving operations to the extent feasible. Complementary investigations would be performed concurrently from the mission module while in orbit about Mars.

In the supporting technologies area, materials research in the hard lunar vacuum, and repair, construction, and maintenance techniques developed in support of extended lunar missions should be broadly applicable to the critical problem of ensuring equipment availability and mission success in manned planetary exploration.

In view of the relative remoteness of Mars, the potential utilization of Martian resources will be of special interest in planning the long-term manned space program. Consequently, resources exploration and exploitation techniques developed for and during extended lunar exploration should be significant to planetary exploration and development.

Thus, the lunar exploration program should be considered not only as a means of achieving intrinsic objectives but as a vital step in an evolutionary long-range space exploration program.

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